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OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 22

JOSEPH STANLEY-BROWN, *Editor*

NEW YORK
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1911

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PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues annually a single serial octavo publication entitled Bulletin of the Geological Society of America, the edition being 555 copies. The first twenty volumes of this serial consist of *proceedings* and *memoir brochures*, the former containing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for publication. Beginning with volume 21 the method of issuing the Bulletin was changed to four parts per year, at intervals of three months each. A small supply of authors' separates of the longer articles will be kept for sale by the Secretary.

The Bulletin is sold at the following prices: To Fellows, institutions, libraries, and persons residing outside of North America, seven dollars and fifty cents ($7.50) per volume; to persons in North America not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows). These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Orders should be addressed to the Secretary, whose address is care of the American Museum of Natural History, New York, N. Y., and drafts and money orders should be made payable to *The Geological Society of America.*

Description of the Published Volumes.

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Brochures of Volume 22

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Proceedings of the Twenty-third Annual Meeting of the Geological Society of America, held at Pittsburgh, Pennsylvania, December 27, 28, and 29, 1910. E. O. Hovey, *Secretary*	1–84	1–6	....	$1.00	$1.50
Proceedings of the Second Annual Meeting of the Paleontological Society, held at Pittsburgh, Pennsylvania, December 28–29, 1910. R. S. Bassler, *Secretary*	85–102	....	....	.20	.30
Origin of the thermal waters in the Yellowstone National Park. Arnold Hague	103–122	....	....	.20	.30
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Pre-Glacial course of the Upper Hudson River. W. J. Miller	177–186	....	1	.10	.15
Aggraded limestone plains of the interior of Bahia and the climatic changes suggested by them. J. C. Branner	187–206	14–17	1–2	.30	.45
Aftonian mammalian fauna, II. Samuel Calvin	207–216	18–24	....	.30	.45
* Conference on the faunal criteria in Paleozoic paleography. R. S. Bassler, *Secretary*	217–280	....	....	.65	.90
Revision of the Paleozoic systems. E. O. Ulrich	281–680	25–29	1–19	4.15	6.20
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Abstract of papers presented at the Twenty-third meeting of the Society, but not published in full in the preceding pages of this volume, together with discussions of papers as far as preserved. E. O. Hovey, *Secretary*	715–738	....	....	.25	.35

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bioliographically distinct from the brochures issued by the Society.

* Under the brochure heading is printed Proceedings of the Paleontological Society.

The following separates of parts of volume 22 have been issued :

Editions uniform with the Brochures of the Society

Pages	85–102,		80 copies,	March	31, 1911.
"	103–122,		150 "	"	31, 1911.
"	123–176,	plates 7–13,	130 "	May	10, 1911.
"	177–186,		60 "	"	22, 1911.
"	187–206,	" 14–17,	180 "	"	23, 1911.
"	207–216,	" 18–24,	130 "	June	14, 1911.
"	217–280,		155 "	"	23, 1911.
"	281–680,	" 25–29,	80 "	August	31, 1911.
"	681–686,	" 30–31,	150 "	December	7, 1911.
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Special Editions†

Pages	4– 8,	plate 1,	30 copies,		March	31, 1911.
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Page	737,		50 "	"	"	15, 1911.

†Bearing imprint [From Bull. Geol. Soc. Am., Vol. 22, 1911], and sometimes including fractional pages.

‡These separates bear upon the cover

PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

[Reprinted from the Bulletins of the Geological Society of America, vol. ——, pp. ——, pls. ——, (Date)]

CORRECTIONS AND INSERTIONS.

Although the usual requests for corrections and insertions were sent out to the contributors to Volume 22, no replies were received prior to going to press.

BULLETIN

OF THE

Geological Society of America

VOLUME 22 NUMBER 1
MARCH, 1911

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY
MARCH, JUNE, SEPTEMBER, AND DECEMBER

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

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NOTICE.—In accordance with the rules established by Council, claims for non-receipt of the preceding part of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 22, PP. 1-84, PLS. 1-6 MARCH 31, 1911

PROCEEDINGS OF THE TWENTY-THIRD ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT PITTSBURGH, PENNSYLVANIA, DECEMBER 27, 28, AND 29, 1910.

EDMUND OTIS HOVEY, *Secretary*

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Session of Tuesday, December 27

The first session of the Society was called to order at 10.30 o'clock a. m., Tuesday, December 27, in the lecture-room of the Carnegie Museum, Pittsburgh, Pa., by President Hague. A cordial address of welcome was given by Mr. W. N. Frew, President of the Board of Trustees of the Carnegie Institute, in which were outlined some of the numerous activities of the Natural History Museum, the Library, the Art Museum, and the Department of Music and the Technical Schools, and a fitting response was made by President Hague.

The Secretary then presented the printed report of the Council, which by vote was laid upon the table till Wednesday morning.

ELECTION OF AUDITING COMMITTEE

The Auditing Committee was then elected, consisting of James F. Kemp, I. C. White, and S. F. Emmons, and the Treasurer's report was referred to it.

ELECTION OF OFFICERS

The Secretary declared the vote for officers for 1911, the regular ticket as prepared by the Council being elected, as follows:

OFFICERS FOR 1911

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W. M. Davis, Cambridge, Mass.

First Vice-President:

William North Rice, Middletown, Conn.

Second Vice-President:

William B. Scott, Princeton, N. J.

Secretary:

Edmund Otis Hovey, New York, N. Y.

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Joseph Stanley-Brown, Cold Spring Harbor, N. Y.

Librarian:

H. P. Cushing, Cleveland, Ohio.

Councilors:

Heinrich Ries, Ithaca, N. Y.
A. H. Purdue, Fayetteville, Ark.

ELECTION OF FELLOWS

The Secretary then announced the election in due form of the following Fellows:

Barnum Brown, A. B., American Museum of Natural History, New York, N. Y.
Charles Albert Davis, A. B., A. M., Ph. D., 1733 Columbia Road, Washington, D. C.
Bashford Dean, A. B., A. M., Ph. D., Columbia University, New York, N. Y.
William Jacob Holland, A. B., A. M., Carnegie Museum, Pittsburgh, Pa.
Louis Hussakof, B. S., Ph. D., American Museum of Natural History, New York, N. Y.
Olaf August Peterson, Carnegie Museum, Pittsburgh, Pa.
Hervey Woodburn Shimer, A. B., A. M., Ph. D., Massachusetts Institute of Technology, Boston, Mass.
George Reber Wieland, B. S., Ph. D., Yale University, New Haven, Conn.

ELECTION OF CORRESPONDENTS

The following Correspondents were likewise declared to have been duly elected:

Dr. Giovanni Capellini, Professor of Geology at the University, Bologna.
Dr. Gerhard De Geer, Professor of Geology at the University, Stockholm.
Dr. H. Rosenbusch, Professor (retired) of Geology and Mineralogy at the University, Heidelberg.
Dr. Emil Tietze, Director of the Imperial Royal Geological Survey, Vienna.
Dr. Th. Tschernyschew, Director of the Imperial Geological Survey, St. Petersburg.
Dr. A. Michel-Levy, Director of the Geological Survey of France, Paris.

Announcement was then made that the Society had lost the following Fellows by death during the year 1910: William Phipps Blake, Franklin R. Carpenter, J. C. K. Laflamme, William H. Niles, David Pearce Pen-

hallow, William G. Tight, T. C. Weston, and Robert Parr Whitfield. Memorials of deceased Fellows were then presented as follows:

MEMOIR OF J. C. K. LAFLAMME

BY JOHN M. CLARKE

Joseph Clovis Kemner Laflamme was born at the little village of Saint Anselme, Dorchester County, Province of Quebec, September 19, 1849. His father was David Kemner Laflamme; his mother, Marie Josephte Jamme. After a usual course in the parochial schools he entered the Petit Seminaire of Quebec, and subsequently the arts course in the Laval University, from which he graduated in 1868, taking his master's degree in 1884. Entering the Grand Seminaire for the theological course, he took his bachelor's degree in 1871, his licentiate in 1872, and his doctorate in 1873. In 1872 he was ordained priest, and directly thereafter appointed professor of geology and physics in Laval University. He was successively director and superior of the seminaire, dean of the arts faculty of the university, and twice and for many years rector of the university. He was one of the founders of the Royal Society of Canada, its president in 1891, in the same year being the official delegate of Canada at the International Geological Congress at Washington, and in 1897 was one of the vice-presidents of the Saint Petersburg Congress. He was designated in 1892 Bishop of Chicoutimi, a preferment he declined, and in 1894 he was appointed by the Pope protonotaire apostolique, a dignity which carries with it the title of monseigneur, by which he had become generally known. He was a director in the Canadian Forestry Association, a chevalier of the Legion of Honor, a member of the Geological Societies of France and of Belgium, as well as of several other dignified organizations. In the year of his second rectorship he retired from his office on account of the growing severity of a malady from which he had long suffered, and after protracted treatment at the hospital and the seminary, he died on July 6, 1910, in his sixty-first year, at the Grand Seminaire, which had been the home of his life.

Thus the brief chronology of a strong and fertile life, a life whose phases are so unusual in the annals of American geology as to be of especial note and inspiration.

Monseigneur Laflamme was first of all a true-hearted priest, beyond reproach in his devotion to his church, her ordinances, and her great aims. In any estimate of the influence of his apostolate in science this prime factor must not be overlooked. Second only to this, he was an

J. C. K. Laflamme

inspired and devoted teacher. His serenity of demeanor, his vivacity of expression accompanying precision of thought, his very wide familiarity with many branches of natural science in his mastership of one, his sympathy with the enthusiasms and ambitions of youth, made his courses of instruction much sought in seminary and university and evoked the loyalty and admiration of two generations of students.

Beginning his teaching of science as a professor in the university when he was only twenty-two, he never would permit himself, as the advancing years brought to him duties of administration, to be cut off from his instructional contact with the students, and it was with utmost reluctance on his part that he consented to abbreviate these functions in order to assume the rectorship of the university. And for a like reason, feeling convinced that he might serve his church more effectively through his chosen channels of instruction, he declined the bishopric of Chicoutimi. Professor Laflamme believed that a teacher in a dignified and influential university should strengthen by breadth of his general culture his special vigor along the line of any chosen pursuit. He was thus a profound student armed with a great library and so absorbed in the pursuit of the wider bearings of his science that to pass the doors of his office and study required something more than the usual conventional knock. His eager application of his knowledge to all that was human made him not alone a man of broad and refined culture, but a dignified and learned savant. Whoever had the good fortune to know him, to pass those doors of his study which swung so heavily on their hinges, found him to those he intrusted with his confidence alert, sparkling, responsive, and inviting in his conversation, which always took an elevated plane and was facilitated by his hospitable deference to our Lady Nicotine. But he was not always easy to reach and seldom at first receptive. One of his colleagues[1] has spoken thus of him:

> "The first contact with him was rather deceiving. He was not a man to unbosom himself to the first comer. A sagacious observer, very reserved, letting his man show himself, this cool scrutator of hearts excelled in piercing human masques. It was not easy to impose upon him. The vain man who ventured to parade himself before him did it only once. At the first boast, a single word spoken in that simple tone which Mgr. Laflamme affected, pitilessly punctured the balloon launched by imprudent hands. And what remained in the chair, after this enlightening word, of the visitor who had called only to dazzle, was of little account in the rest of the interview."

The honors of his career have been mentioned in part, and some of

[1] Rev. Antonio Huot in Revue Franco-Americaine, August, 1910.

them will show the esteem in which his geological service was held by the provincial government of Quebec and by the Dominion.

It is to his geological work that we ought on this occasion direct our special attention and estimate. Monsigneur Laflamme was active in geological matters of public concern. Preliminary to the meeting of the commissions of the two countries interested in the reduction of water abstraction at Niagara, he made a careful study and report upon the conditions there; he investigated the abstraction of water from Montmorency Falls by the Quebec Light and Power Company, and his report led to the correction of a public wrong and restored to a singularly beautiful spot some of the glory of which it had been robbed. For the Geological Survey he made a report on the Saguenay and Lake Saint John region. Most of his special papers were printed in the Proceedings of the Royal Society of Canada, and the unusual scope of his interest is well indicated by their subjects. He discusses the occurrence of gold, of emerald, and of natural gas in Quebec; the contact of the crystallines and paleozoics; the landslides of Saint-Luc-de-Vincennes and of Saint Alban, and the effects of the latter on the drainage; the earthquakes of Quebec; the meteorology of Quebec, and the Quaternary deposits of Anticosti Island. In later articles he has written on the Laurentides and on the Notre Dame or Shick-Shock Mountains of Gaspé. These may be regarded as indicating the immediate expression of his activity in the science we here cultivate, but it would be scant justice to Laflamme should we pass unnoticed his text-books, "Elements de minéralogie et géologie," "Notions sur l'electricité et le magnetisme."

But Laflamme was a public man acutely interested in affairs and civic concerns, and this activity, supported by his great learning, gave him general recognition among the influential and distinguished leaders in French Canada. He was a leading organizer of the Congress of Americanists held at Quebec in 1906, and his late and most fruitful propaganda was on behalf of forestry and a forestry school for the Province of Quebec. Monseigneur Laflamme's personal modesty kept him under some restraint before the public, but he was a charming and compelling speaker. In the effort to arouse a public sentiment favoring scientific forestation he put aside his reserve, made many effective public appearances, earned the applause of his colleagues, and with their help won and lived to see the establishment of a forestry school in his own province and at his own university. It has been suggested by his colleagues of the forestry department of Quebec that this new institution be known as the Laflamme School of Forestry. Such an act would be a gracious tribute

to a many-sided man of science and culture whom we are fortunate to have numbered in the roll of American geologists.

The widespread expression of grief at his death, the common testimony of the press to his achievements and worth as a citizen were supplemented by the distinction of his funeral, at which the Governor-General was specially represented by a judge of the Supreme Court, supplemented by the official and personal presence of the governor of the province, its prime minister and members of the Federal Cabinet, by messages of regret and grief from the premier and many of the distinguished officials of the Dominion. His death has been generally regarded as a national loss, and to the science which he loved and uplifted beyond the plane of specialism it is undeniably a severe deprivation.

In his intimate memorial notice of his former colleague at Laval, Dr. T. Sterry Hunt, Monseigneur Laflamme said, as we may here say of him: "La personne disparue est bien oubliée; mais le fruit du travail demeure."

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MEMOIR OF WILLIAM HARMON NILES[2]

BY GEORGE H. BARTON

William Harmon Niles, professor emeritus of geology at the Massachusetts Institute of Technology, Boston, Massachusetts, died at the Copley Square Hotel, Boston, September 12, 1910, after an illness with a complication of diseases of nearly two years. During this period of illness the death of his wife was a very severe shock which probably hastened his own death.

Professor Niles was the son of Rev. Asa and Mary A. (Marcy) Niles, and was born at Northampton, Massachusetts, May 18, 1838. From his father he inherited a retentive memory and from his mother his ready use of language and his fondness of nature. His inherited traits of mind were manifested very early in life. In boyhood he was fond of collecting minerals and plants in the region of his home, and his subsequent career was foreshadowed by his youthful recreations. At the age of sixteen he had a good collection of the minerals of Worthington and of four neighboring towns, which he had gathered, arranged, and labeled.

Owing to the limited means of a New England clergyman, he was obliged to work his way through school and college. He began teaching in Worthington at the age of seventeen, and taught there four consecutive winters, at North Blanford two terms, followed by one at North Becket. Throughout his life Professor Niles often referred to this as the most vivid incident in his life, and from him the present writer has a vivid impression of that boy's thoughts and aspirations as he walked five miles across the hills of western Massachusetts to take charge of his first school, in which many of the pupils were older than himself. During the summer seasons at this time he worked regularly upon his father's farm. It was not until he was twenty that he received his first school instruction in any science. At that time he went to the Wesleyan Academy a Wilbraham, Massachusetts, but he could not remain for consecu-

[2] Presented by title.

tive terms because of lack of means. There he received instruction, and, what was perhaps more valuable, encouragement from his mother's brother, Oliver Marcy, LL. D., later of Northwestern University, at Evanston, Illinois.

It was with Doctor Marcy's advice that he went to Cambridge to become a pupil of the distinguished Prof. Louis Agassiz. At the Museum of Comparative Zoology his work was largely zoological, but geological studies were his favorites. It was while there that he developed a decided fondness for physical geography, and for the remainder of his life that was his favorite branch of science. As a student of the Lawrence Scientific School, he attended two courses of lectures in comparative anatomy by Prof. Jeffries Wyman, three courses in botany by Prof. Asa Grey, a course by Professor Lovering, and he took two courses in mineralogy under Prof. Josiah P. Cook. His special studies under Professor Agassiz were of the nature of investigations, often without any aid from books. For the first lesson a pile of fish bones was placed in front of him, with no instructions except that he was told to see what he could make out of them. After several days of careful observation, comparison, and thought he succeeded in arranging and classifying the bones to the satisfaction of the master and much to his own encouragement. In this way he carefully studied modern corals and fossil mollusks of the Mesozoic. His most extended and detailed researches were upon the crinoids, and it was upon the classification and distribution of this group that his thesis was prepared. He spent six months in Iowa and Illinois studying the noted crinoid collections of Charles Wachsmuth, Doctor Thieme, and Rev. W. H. Barrus, and in making various field studies in geology. As agent for Professor Agassiz, he purchased the last-named collection for the Museum at Cambridge. It was through the highly esteemed kindness of Professor Agassiz and the assistance that he granted him from the Thayer Fund that he was enabled to enjoy such opportunities for four years.

The young student was fortunate in his teachers, who were leaders in their respective sciences, and also fortunate in his association with a group of students, called together largely by the fame of Agassiz, nearly all of whom became prominent as scientists, investigators, or teachers, or both. He was a room-mate and always a close friend of J. A. Allen, curator of the department of mammalogy at the Museum of Natural History, Central Park, New York City. Other students at the Cambridge Museum with whom he was intimately associated were Alpheus Hyatt, C. F. Hartt, A. E. Verrill, F. W. Putnam, S. H. Scudder, A. S. Packard, Horace Mann, A. S. Bickmore, and O. H. St. John.

Largely by the friendly assistance of Prof. A. E. Verrill he was enabled to spend a year and a half as a student in the Sheffield Scientific School at New Haven, Connecticut, from which he was graduated Ph. B., in 1867. While there he was a working student in Professor Verrill's laboratory. He had mineralogy with Prof. G. J. Brush, French and German with Prof. W. D. Whitney, lectures in physical geography by Prof. Daniel C. Gilman, and in geology by Profs. James D. Dana and O. C. Marsh. His most intimate associates at this time were Sidney I. Smith and William North Rice.

He received the degree of A. M. from Wesleyan University in 1870.

In addition to these preparatory studies and labors, he was further qualified for giving instruction to the students of the Institute of Technology, which later became his life work, by his experience as a teacher and lecturer. He taught in several private schools, and was thus associated with the Gannett Institute for several years. Before leaving Cambridge he had been appointed instructor and lecturer in natural science at the State Teachers' Institutes of Massachusetts. His services in this position were distributed through a period of ten years, during which time he lectured in every portion of the state. In this way he had become widely and popularly known as a lecturer upon geological and geographical subjects.

Under the advice and counsel of Prof. William B. Rogers, founder and first president of the Massachusetts Institute of Technology, he was appointed professor of physical geology and geography at that institute in 1871. For eight years his instruction at the institute was given during the second half of each year, thereby affording him the opportunity of continuing his public lectures.

Feeling that a personal acquaintance with various countries was essential to a teacher of physical geology and geography, he made journeys to Europe, spending portions of three summers among the Alps. There he visited and studied for himself those districts which had been made famous by the studies of his former teacher, Professor Agassiz, and by the investigations of others. His own observations while there led to the publication of his papers, "Agency of glaciers in the excavation of valleys and lake-basins," "Relative agency of the glacial and subglacial streams in the erosion of valleys," and "Occurrence of zones of different physical features upon the slopes of mountains."

He twice visited Holland, that he might observe the peculiar relations there existing between physical features, geological changes, and human life. His observations in that country were very useful in his geographical teaching at the institute. His illustrated lectures on "Holland and

its people" and on his experiences among the Alps were so well received and so widely delivered that they yielded an important part of his resources for travel and extended geographical study.

He also gave courses of lectures before public audiences. Three courses of twelve lectures each were delivered at the Lowell Institute in Boston, "Geological history, ancient and modern," "The atmosphere and its phenomena," and "Physical geography of the land" being the respective subjects. Other courses were given for the Boston Society of Natural History, the Teachers' School of Science, and the Appalachian Mountain Club. Two courses were given at the Peabody Institute in Baltimore, and similar courses at Wakefield, Jamaica Plain, Charlestown, and Framingham. The success of his lectures was such that he was sometimes called to speak from fifty to one hundred times in a single season.

During this time he became interested in the evidences that portions of the crust of the earth, especially those in Massachusetts, which are usually regarded as stable, are really affected by an energy sufficient to sometimes fracture and dislocate them. As a result, he published the following papers: "Peculiar phenomena observed in quarrying," "Effect of pressure upon rocks," "Further notice of rock movements at Monson, Massachusetts," "On some expansions, movements, and fractures of rocks observed at Monson, Massachusetts," and "The geological agency of lateral pressure exhibited by certain movements of rocks."

When Dr. T. Sterry Hunt retired from the chair of geology at the institute, in 1878, Professor Niles was appointed professor of geology and geography, with W. O. Crosby as assistant in geology. From this time these two were constantly associated, and the department of geology as it stood in 1902 was the result of their combined efforts. In 1878 there were no arranged collections at the institute, and very few appliances for instruction in that branch. In 1902 the collections illustrating structural geology, mineralogy, petrology, economic geology, and palæontology contained over thirty thousand specimens, well arranged and mostly labeled. Professor Niles' principal share in this work was devoted to the collection of paleontology.

After the founder of the institute, President Rogers, probably no one man has done more to upbuild the institute than did Francis A. Walker when he was its president. That the institute was so fortunate as to obtain General Walker for its president at a most critical period in its history thanks are due to Professor Niles, as it was he who first suggested the consideration of General Walker's name. The reply to this suggestion was that there was no probability that he could be obtained. By

permission, but of his own accord, Professor Niles went to New Haven and, as the result of a personal interview with General Walker, brought back the reply that opened the way by which the institute secured General Walker for its president.

In 1902 Professor Niles retired from active teaching at the institute, and was made professor emeritus.

Besides his position at the institute, Professor Niles held many others of honor and importance. He was for five years the president of the Boston Society of Natural History, three times president of the Appalachian Mountain Club, president of the New England Meteorological Society, and president of the Lawrence Scientific School Alumni Association. He was professor of geology in Boston University from its first graduating class till 1901. The following, taken from the records of the trustees of Wellesley College at the time of his retirement from that institution, in June, 1908, speaks of his work there:

"William Harmon Niles, B. S., Ph. B., M. A., LL. D., joined the faculty of Wellesley College in 1882 as lecturer in geology. Classes at once responded to his skilled touch. Interest so increased and work so strengthened that in 1888 the one course broadened into a department of which Doctor Niles was made the head. In 1891 Doctor Niles accepted the chair of geology, which was then established, and he has remained in full charge of the work, now expanded into four courses. . . .

"The services of this esteemed officer have not been confined to class-room duties merely. Professor Niles came to Wellesley in a day of beginnings. His standing among scientists, the weight of his judgment, the intimacy of his connection with a great technological school, all lent themselves effectively to the work of framing suitable laws of growth for the young college. In all its succeeding history the college has enjoyed from Professor Niles sympathy, support, and counsel, which have been highly appreciated." [4]

Professor Niles was sought by other institutions several times during his connection with the institute, but always declined. He was especially requested by Prof. Arnold Guyot to take the place vacated by the retirement of the latter from the chair of geography at Princeton.

He maintained active relationships with scientific societies. He was a Fellow of the American Academy of Arts and Sciences, Fellow of the Geological Society of America, Fellow of the American Association for the Advancement of Science, member of the National Geographic Society, member of the Boston Society of Natural History, member of the Appalachian Mountain Club, member of the New England Meteorological Society, corresponding member of the New York Academy of Sciences, etcetera.

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[4] See College News, vol. 10, No. 6.

Although Professor Niles has left little literature to recall his name to succeeding generations of scientists, he has left an impress upon every earnest student that came under his instruction that has broadened that student's life. It is in this way that the world is especially richer that Professor Niles has lived and been a part of it. Very many of his former students might be quoted, but two quotations must suffice. Each of the following testimonials is from a man now of high rank in the work of the world and in scientific circles:

"Professor Niles lives in the memory of the men and women who, as students, came under his influence, and his ideals are reflected in their acts. It is not so much through his writings that he molded opinions and character as by daily cheering contact with his pupils and his colleagues; by the hearty zeal and willing energy with which he took up and carried through the innumerable details which fell to his lot, or which he gladly assumed, because it appeared that no other person could or would give the needed attention. . . . In looking back over a period of many years of personal acquaintance, ripening into friendship, we may not recall the title of a single article or scientific paper by Professor Niles or any particularly striking or original work of his, yet the memory retains the impression of a long series of acts of kindness, of sound advice, of cheering, yet direct, criticism, founded upon a full knowledge of many subjects, all of which in the aggregate has been of indescribable value to the students who came in contact with him. . . . His attitude towards scientific work was conspicuously that of a fellow-student and instructor. Whenever he acquired any item of interest his first impulse was not to hoard this, to build up into a book or article, but it was his delight to discuss it with his friends, and especially to put the matter in a form attractive to students and to others who might share with him the enjoyment of the added information.

"As an instructor and lecturer, he rose above the dry technical presentation of a subject, and clothed the otherwise uninteresting details in language such that none but the most inert could fail to appreciate. . . . Yet, in spite of the attractive form, the real solid information was there, properly clothed or pictured.

"I first knew Professor Niles when I took his course in physical geography, in 1875, at the Institute of Technology. I think I may say without exaggeration that this course was one of the most inspiring and suggestive courses which I ever attended; indeed, it set me thinking and studying in a direction which, through all the subsequent years, afforded me much pleasure as well as profit.

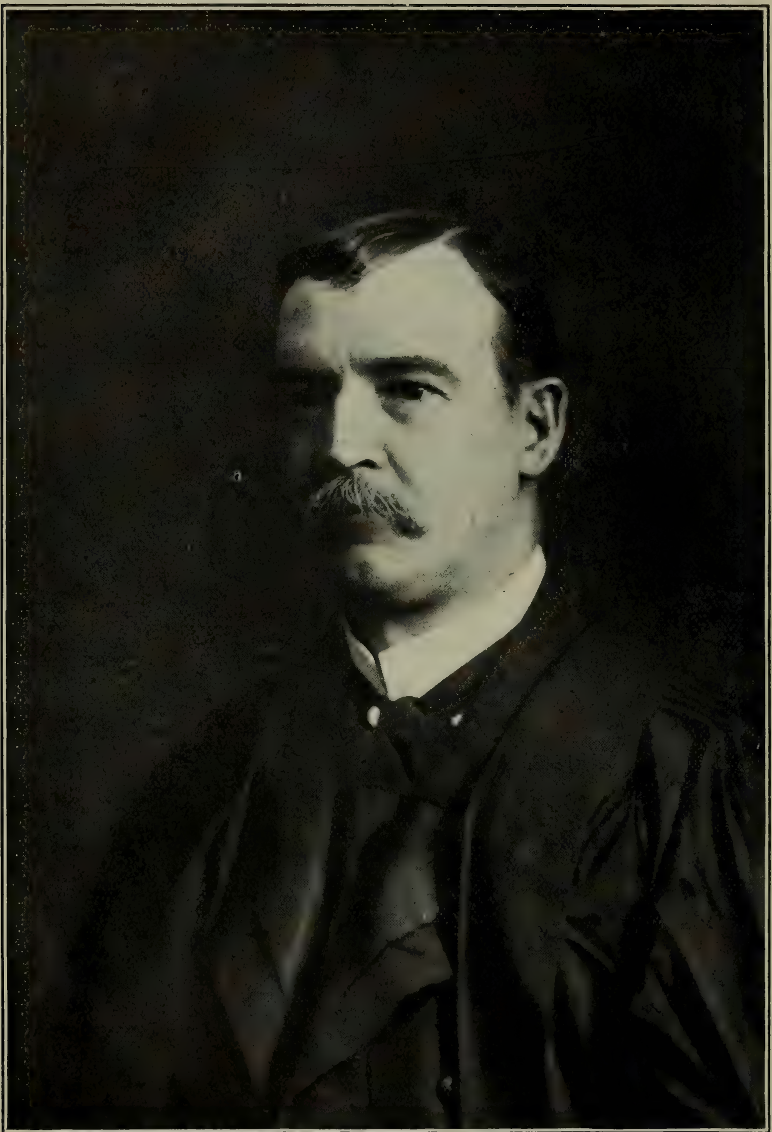
"Professor Niles did not use any text-book, but we were required to take notes and were expected to write them up. I had always had a liking for topics of this kind, and under his stimulating assistance I did a great deal of outside reading in connection with his course and took pains to write up the notes as carefully as I could. There is, of course, little mental training involved in a lecture course; each student gets what mental training he receives by himself in writing up the notes and studying the references. But Professor Niles's lectures were so suggestive, and he was so willing to give advice with

reference to outside reading, that I soon became deeply absorbed in the subject and have always maintained my interest in it. I shall never forget the pride which I felt when, returning to me the notes which I had written up, he sent with them a little slip of paper, upon which he had written, 'I thank you for your interest and support.' I still have the notes and the slip of paper.

"Professor Niles won the affection of his students in an extraordinary degree, and he impressed them at the outset with the fact that he was endeavoring to help them and to interest them and to stimulate them to pursue the subject further than he was able to carry it, and I think he succeeded better than most teachers. He always had a kindly word for every one, took a broad view, and did much, I believe, to broaden the scientific outlook of those who were fortunate enough to attend his courses."

The present writer first met Professor Niles in 1878, when he was under his instruction at the Institute of Technology. At this time began a friendship lasting through the student days, through life abroad, and then through the close companionship of first assistant and then colleague at the institute, that has been one of the most highly prized possessions of the writer's life. This close friendship gave a still deeper insight into the character of the man than could be obtained even by the most enthusiastic admirers among his students, for Professor Niles was always reserved concerning himself. Underneath the genial exterior, the ready laugh, and the habit of story-telling that sometimes was misinterpreted, lay the man of deep and earnest convictions and of very high ideals. Nothing pained him more than to have a student manifest a tendency toward low ideals, and his fatherly interest in such a case and his kindly counsel were marked features in his character. He was a constant and very active member of the scholarship committee of the faculty and was exceptionally attentive to the needs of students struggling against financial difficulties. Always considerate of every one, always looking for the best in others, he was very sensitive to adverse criticism when his own acts were misunderstood, but he bore the hurt with a smiling face, and only his closest intimates knew how deep was the cut which lurked below.

Professor Niles married, in 1869, Helen M. Plympton, the daughter of a prominent physician of Cambridge. Throughout their forty years of wedded life she was his constant companion at home and on his journeys abroad. Her life was largely devoted to a thoughtful care of his needs, and her death was the severest blow of his life. Unfortunately there were no children to bless the union, and her death left him to the care of friends till the end came, but a short time after.



D. P. Penhallow

MEMOIR OF DAVID PEARCE PENHALLOW[6]

BY ALFRED E. BARLOW

Professor Penhallow, who for twenty-seven years (1883-1910) occupied the chair of botany at McGill University, Montreal, died suddenly at sea on October 20, 1910, while on his way to England.

His passing away was, however, not altogether unexpected, for, following a serious breakdown in October, 1909, he was obliged to take a complete rest for many months. This enforced absence from professorial duties, although not bringing about the result desired or expected, nevertheless gave promise that with a longer holiday abroad Doctor Penhallow would finally regain his usual health and vigor. He had, accordingly, sailed for England in company with Mrs. Penhallow with this object in view. His sudden death has elicited expressions of the deepest sympathy and regret both from his pupils and his colleagues who had been associated with him both in the work of the university and in the activities of the numerous scientific societies to which he belonged.

During his twenty-seven years of loyal service to Canada, to Montreal, and to McGill University in particular, he maintained his allegiance to his native country and cherished the traditions of his early environment. Doctor Penhallow was born on May 25, 1854, at Kittery Point, Maine, on the opposite side of the Piscataqua River from the city of Portsmouth, New Hampshire. Descended from a long line of ancestors, many of whom for over two hundred years had been prominent in the public affairs of Portsmouth, he inherited their public spirit and love of enterprise, together with those habits of perseverance and tireless industry which had made them to be included in the honor roll of its citizens and helped him so materially in his palaeobotanical work, a branch of science very little understood or studied, and possibly less appreciated.

At the age of nineteen (1873) Doctor Penhallow graduated (B. S.) from Massachusetts College. Later (1888) he received the degree of B. S. from Boston University. In 1876 he was awarded the degrees of B. Sc. and M. Sc. by McGill University, and in 1904 was made a doctor of science (D. Sc.) of the same university.

In 1876 he was appointed professor of botany and chemistry at the Imperial College of Agriculture at Sapporo, in Japan, where he remained until 1880, serving as acting president of the college in his final year of office. Like many other young Americans to whom Japan turned in her anxiety to learn everything possible of western thought and civilization,

[6] Presented by title.

he grew to love the country and its inhabitants. Long after his return to America he kept in communication with many of his Japanese friends and students, many of whom afterwards became well known men of science. After a short time spent as an instructor in physiological botany at Harvard University, he was appointed in 1882 as botanist and chemist at the Houghton Farm Experiment Station, a position he held until his appointment as professor of botany at McGill University, in 1883.

The duties of his professorship brought him into close association with Sir William Dawson, who was at that time principal of McGill University, and Professor Penhallow became an enthusiastic student of palaeobotany. In collaboration with Sir William Dawson he prepared and published several papers dealing chiefly with the "Erian (Devonian) plants from various parts of the world as well as with the Pleistocene flora of Canada." Then followed a long series of notes, articles, and government reports by Doctor Penhallow himself. Some of these earlier productions were the direct result of the study of problems which had been suggested or brought to his attention by reason of his earlier investigations with Sir William Dawson, but on his own initiative he soon began to break new ground.

Among the most interesting of his earlier papers are descriptions of the Nematophyton, or Nematophycus, as it was called by Carruthers. In 1856 Sir William Dawson gave the name of *Prototaxites* to "large masses of black silicified wood" which had been discovered by Sir William Logan in the Devonian sandstones of Gaspé. His conclusions that they were related to the modern group of Texas, and that "they may represent a leading type of forest vegetation in the Silurian and early Devonian," were disputed by Carruthers, who believed them to be gigantic fossil seaweeds. In 1888, after this fossil had been found to embrace a number of distinct species and to be of quite widespread occurrence in Devonian rocks, Doctor Penhallow confirmed the view advanced by Carruthers that "this plant is in reality an Alga, and allied to the Laminaria of our modern flora." Likewise, his paper upon "The North American species of Dadoxylon" is a scholarly treatise which, in so far as is known concerning these plants, presents a clear conception of their true character and relations. His lucid description of the manner in which some of the marsh lands on the coast of New England have originated and developed supports the conclusions of other observers that the eastern coast line of North America is slowly subsiding.

History, whether written upon the rocks or buried in forgotten volumes, was particularly attractive to Professor Penhallow. He traced each subject with which he busied himself as far back as accessible litera-

ture would permit. Two of his papers represent a complete "Review of Canadian botany" from the time of the first settlement of New France until 1895. The bibliography contains many interesting names, many of which are preserved in the names of familiar American plants.

In later years Doctor Penhallow turned his attention to the Cretaceous and Tertiary floras of Canada, a subject of which, prior to his investigations, very little was known and on which he became the leading authority. This work is of great value apart from the careful and detailed description of fossil forms because he attempted, when possible, to trace the genetic relationship between fossil and modern types and to apply the collected data to a determination of stratigraphic position and succession.

The nature of this work demanded a very intimate knowledge of existing varieties of woods, and as a result of many years of studying the stems of fossil and extant conifers he produced that tribute to patient and persistent toil—his book on "North American Gymnosperms." The first part of this book is devoted to a discussion of the minute anatomy of the stem, the probable lines along which the various elements of structure have developed, and the relative durability of woods and their preservation as fossils. Assuming the attitude that "internal structures must always have precedence over those of external morphology in questions of classification," the second part is so arranged that from a microscopical examination of thin sections of the wood the species may be quite readily determined.

Doctor Penhallow had great administrative ability. The last few years (from 1907) were devoted as director to the organization and arrangement of the Atlantic Coast Biological Station at Saint Andrews, New Brunswick. He was a Fellow of the Royal Society of Canada and president of Section IV in 1896-1897. He was also president for several years of the Natural History Society of Montreal, and in 1899 of the Society of Plant Morphology and Physiology. From 1902-1904 he was chairman of the British Association Committee on the Ethnological Survey of Canada, and in 1909 acted in a similar capacity to the American Biological Research Stations. He was vice-president of the section of botany at the British Association meeting in 1897 and a trustee of the Marine Biological Laboratory, Woods Hole, Massachusetts. In addition he was a Fellow of the American Association for the Advancement of Science and vice-president in 1909, Société Naturelle (vice-president in 1907 and president in 1908), Botanical Society, Forestry Association, Academy of Political and Social Science, New England Botanical Club, non-resident life member of the Massachusetts Hab.—— Society, associate member of the Boston Society of Natural History, Nova Scotia

Fruit Growers' Association. In 1907 he was elected a Fellow of the Geological Society of America.

From 1888-1890 he edited the *Canadian Record of Science;* from 1897-1907 he was associate editor of the *American Naturalist,* and from 1902-1907 was editor of palæobotany for the *Botanisches Centralblatt.*

The following is a list of his more important publications:

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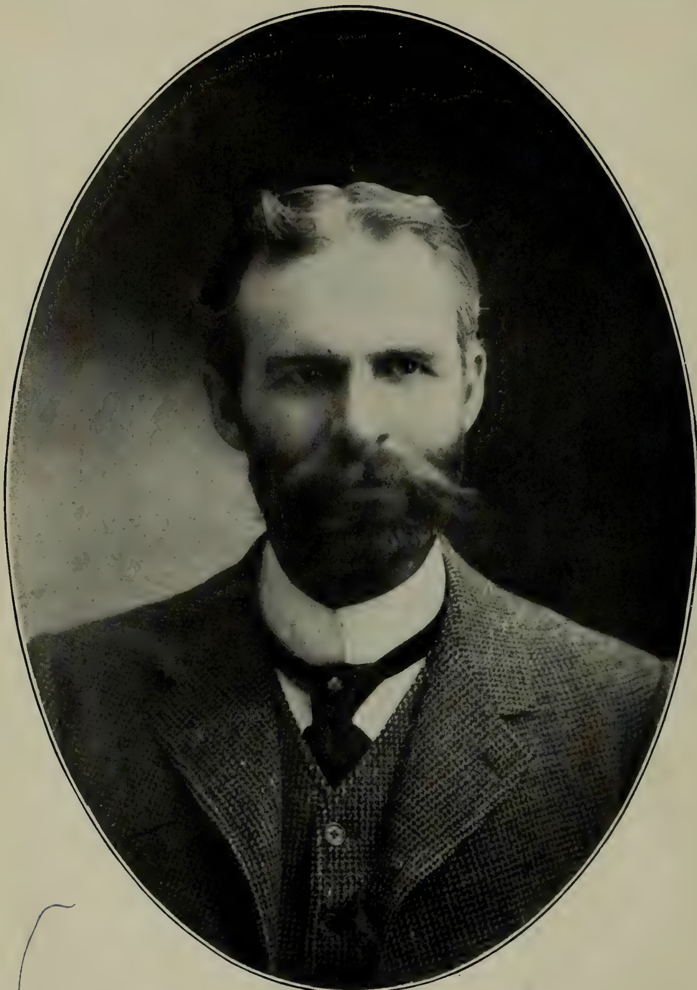

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MEMOIR OF WILLIAM GEORGE TIGHT

BY J. A. BOWNOCKER

William George Tight was born near Granville, Ohio, March 12, 1865. His early life was passed on a farm in the manner customary for boys in central Ohio a half century ago. Denison University was located near by, and there Tight wended his way, graduating in 1886. Coming under the influence of Dr. C. L. Herrick, then at the threshold of his career, Tight developed a fondness for geology and biology, and remained for a year of advanced study, being one of the first two resident graduate students to enroll in Denison University. That he made a good impression on Doctor Herrick is shown by the fact that in 1890 he was appointed instructor in geology. Two years later he was promoted to an assistant professorship in geology and botany, and in 1898 was made professor of geology and botany, retaining the chair until 1901, when he resigned to accept the presidency of the University of New Mexico.

While he gave courses in both geology and botany, the former appealed to him most strongly, and he was quick to seek opportunities to extend his knowledge, first at Harvard and later at Chicago, where he received the Ph. D. degree in 1901. While at Harvard he became specially interested in questions of drainage changes, and, returning to Ohio, he found problems of this type on all sides. His vacations, all too short, he spent in the field, and in quick succession published in the Bulletin of Denison University and elsewhere a number of short papers on drainage modifications which marked distinct contributions to the geology of Ohio. Later he studied the history and development of the drainage of southeastern Ohio and adjacent parts of West Virginia and Kentucky, and his results may be found in Professional Paper 13 of the U. S. Geological Survey. This was by all odds the most comprehensive of Tight's contributions to geology, and in the writer's judgment it ranks high among the best papers that have appeared in that general field.

As already stated, he assumed the duties of president of the University of New Mexico in 1901, retaining that position eight years. In that position he seems to have worked with the same enthusiasm that he did in the geological field, and he was as successful as conditions made possible. He enlarged the faculty, added to the equipment, widened the courses of study, and at the same time kept distinctly in mind the needs

of the people whose support made the institution possible. Through his influence the board of trustees adopted the Pueblo style of architecture for the university, making it unique in buildings among educational institutions.

Naturally the duties of the executive office checked his work in the field, and I have no information of any large contributions made to geology after he left his native state, though he occasionally presented papers to the Cordilleran Section of the Geological Society, as well as to the parent organization. He had, however, done much field work in the territory and had arranged for a year's leave of absence to continue these studies. Unfortunately his notes were largely destroyed by fire in May last. He also organized the Geological Survey of New Mexico, but before it had gotten on its feet he left the territory, for one of those eruptions so volcanic-like in its severity and all too common in state institutions of the distant West ended his career as a university president.

The last few months of his life were divided between economic geology and insurance, which doubtless he considered simply as a method of earning a livelihood until a suitable opening in geology might be found. For some months he was annoyed by severe headaches and later by stomach disorders, the latter followed by blood poisoning, from which he died on January 15, 1910, in his forty-fifth year.

Doctor Tight was a man of robust physique, tall and athletic, qualities that served him well in the long tramps over the hills of southeastern Ohio and later over the plateaus and mountains of New Mexico. He was an excellent observer and logical thinker. In short, he had the qualities that make a field geologist, and there, in the writer's judgment, should have been his life's work, and this is said without disparagement to his services in the class-room, where he was efficient. His personality was strong. This was well shown at the New York meeting of the Geological Society in 1906, when he extended an invitation to the organization to hold its next meeting at Albuquerque. On account of the remoteness of the place few of the members seemed to prefer it, but Tight presented the matter with such enthusiasm that the invitation was accepted. Commenting on this meeting, the Secretary of our Society writes:[6]

> "Tight worked hard for the success of the Albuquerque meeting, interesting everybody in the town, and even securing concessions from the Santa Fe Railroad that were far greater than the size of the gathering in itself would have warranted. He was everywhere at all times and did everything that anybody could for our comfort and profit. If direction was needed he was the director, and if a camp rustler was called for Tight cheerfully volunteered his services.

[6] Personal letter.

His preparations were so complete in every respect that the Society expressed itself in a formal vote of thanks at the concluding session. In connection with this meeting he organized a very instructive and enjoyable excursion to the Sandia Mountains and another to the Grand Canyon of the Colorado."

Probably this meeting was one of the brightest occasions of his life.

While in Ohio he was active in the State Academy of Science, and served one year as its president. For a number of years he edited the Bulletin of Denison University, and aided in every way in his power the advancement of science in his university and state. In 1905 he was chairman of the Cordilleran Section of the Geological Society.

He was public spirited, and wherever located gave freely of his time in anything that promised to advance the community.

Personally he was affable and retained much of the enthusiasm of youth after he had reached man's estate. Always accommodating, he was loyal to friends, with the minimum of resentment to enemies.

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MEMOIR OF ROBERT PARR WHITFIELD

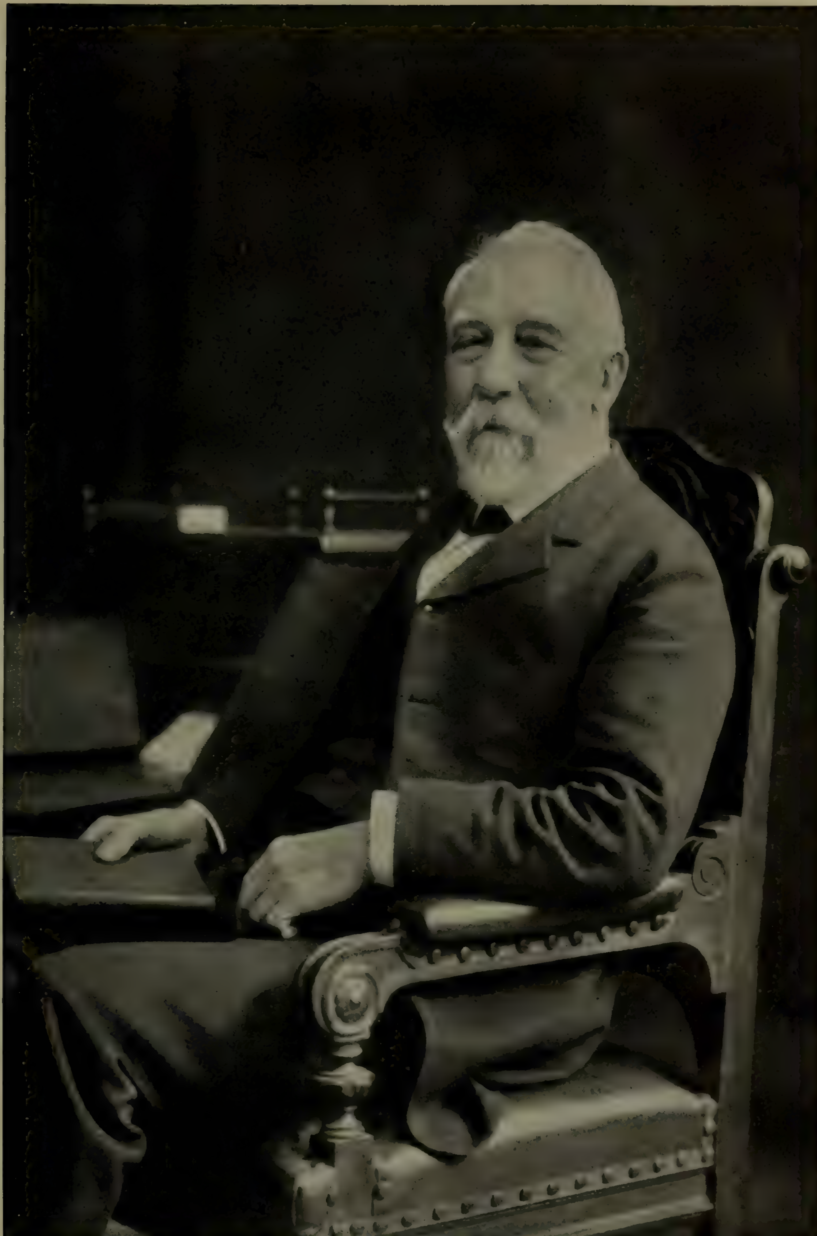
BY JOHN M. CLARKE

This age of general education and of necessary special training for the student of science sees an ever lessening number of men who have done well and deserved well without the full panoply of modern equipment. We have had a goodly array of such men in the history of American science, in whom an inspiring mutation or a favorable inheritance of an instinctive love of nature has successfully overcome the shortages of early training. The departing generation gave us more such men than the present, and perhaps we could find no one career that more signally illustrates this achievement than that of Professor Whitfield.

Through a very long life he displayed not only great assiduity in the pursuit of the occupation to which, by his very good fortune, he was called, but a natural aptitude quite out of the ordinary, even among the trained men of science today. One likes to think, in the presence of what Professor Whitfield did accomplish, of what he might have done had he been blessed with the guidance of thorough education. And one may well reflect how much more would be achieved in our science today if our trained men were more happily endowed with the enthusiasm which knows no bounds of hours or salary.

Robert Parr Whitfield was born at New Hartford, New York, May 27, 1828, and he died at Troy, April 6, 1910, having lived into his eighty-second year. He is buried in the Rural Cemetery at Albany, not far away from Ebenezer Emmons and James Hall.

In the very fact of his great age he takes rank with the two most intimate associates of his earliest work in his science—James Hall, his chief on the New York Geological Survey, and Charles A. White, his companion in arms during their years at Albany. Mr. Whitfield's name is that of one who, at a time when the field of invertebrate paleontology in America was wide open, virgin, inviting, and exceedingly contentious, made noteworthy contributions to morphology under the cover of a greater name, from which he was not released till he had passed middle life. Mr. Whitfield's father, an Englishman, was a spindle maker in a cotton mill. When Whitfield was seven years old his family went back to England with the intention of remaining, but after six years returned



R. P. Whitfield

to Utica, and then the young man was set to learn his father's trade of spindle making. Evidently he cared little for it, as at the age of twenty he was put at work in Chubbuck's manufactory of "philosophical" apparatus—then and for long after a well-known establishment in Utica—and today many of the Chubbuck air pumps, galvanic cells, and generators are to be found in the storerooms of the older academies and colleges of New York. In this establishment he became a partner and had much to do with the manufacture of the Morse telegraphic instruments. But Mr. Whitfield had practically no schooling. Doctor Hovey has quoted Mr. Whitfield's own statement that his entire school training amounted to less than three months, and his achievement therefore is really a matter for wonder and applause. But his love for natural objects, joined with the acquisitiveness that goes with an instinct for natural history, led him early to make collections of the shells, and more particularly of the fossils which abound in that region of paleozoic sediments. Like Marsh, Powell, Orton, Calvin, Walcott, and some other New York men, Whitfield's life was, *mutatis mutandis*, an illustration of the outcome of a favorable environment on an innate proclivity. In the intervals of his shop work he sought out the mollusks of the streams and woods and the fossils in the Silurian rocks, arranged them with nicety, exactness, and keen appreciation of their structural differences, explicating these by drawings, of which he had learned the art in the Chubbuck factory.

His interest in natural science and his skill at drawing had become known to James Hall, then approaching the height of his long and lasting influence on American geology. Hall had a rare and keen insight into the possibilities of young men endowed with zeal for science. He was ever on the lookout for them. It was a singular trait of this man of many singular traits that the scientific assistants he brought about him were soon made fully aware of the fact that they must efface themselves so far as any recognized participation in his official work was concerned, but notwithstanding give their best to his science or accept their congé. All did the former, for there was a contagion in Hall's enthusiasm, and most all got the latter sooner or later; but Whitfield was an exception, remaining with Hall for twenty years and helping to give distinction to the Paleontology of New York by his exquisite drawings and his keen analysis of fossil structures. In 1856 Hall was deeply involved in work; aside from his Paleontology of New York, of the third volume of which he was then bearing the entire expense, as the State appropriations had failed, he was conducting the Geological Survey of Iowa, and when Whitfield arrived in Albany in that year he found his imperious master sur-

rounded with young men—Fielding B. Meek, Charles A. White, and William M. Gabb—all to become distinguished in their work elsewhere, but no one of whom was permitted to look for honors in the official work of his chief. Mr. Whitfield's experience in drawing had been that of a mechanical draftsman, and the first of his work was the explication of the calyx plates in the Iowa crinoids by diagrams, which were so very successful and illuminating that he was soon to have opportunity to carry this work further, for it was about this time that C. A. White discovered in the Hamilton shales near the village of Muttonville the most remarkable colony of crinoids the State of New York has ever produced, and it became imperative to describe them at once, for Billings was just over the fence in Canada, and the paramount law in those belligerent times was priority. So here again Whitfield displayed his exceptional skill in the demonstration of these structures with a success not before attained. Mr. Whitfield was the independent author of only one scientific paper in the reports of the State Museum during his twenty years in Albany—a brief one on the structure of the brachidium of a brachiopod—but he was admitted into partnership with Hall in several papers on the fossils of Ohio, Iowa, and Illinois, on which it is pretty safe to say he did most of the work. The thousands of drawings which Mr. Whitfield prepared for the Paleontology of New York were perfected by an appreciation of the morphology of the structures under study and a sharp eye for details. Hence many of these drawings were the most exact as well as the most highly finished illustrations of paleozoic fossils that had ever been published and were a noteworthy embellishment of the science. He nearly lost his eyesight over his drawings of the graptolites, which were made for Hall's momentous treatise on these organisms for the Canadian survey, but Mr. Ruedemann assures me that these were so remarkable in accuracy, both of detail and general structure, as to give an entirely new conception of these creatures and their mode of growth. These Albany years of Whitfield's life were strenuous times for invertebrate paleontology in New York. Their fire entered into the life of all that shared in them, and though they have gone never to return they have carried their impression well into the present.

In 1872 Mr. Whitfield began to give instruction in geology at the Rensselaer Polytechnic Institute in Troy, where for time out of mind James Hall had been professor of that science. He continued his connection with that institution till his removal to New York. It was this service that gave him the title of Professor, which he always thereafter rightfully cherished. When Dr. A. S. Bickmore was organizing the American Museum of Natural History he succeeded in effecting as the

first large acquisition of scientific material the purchase of the James Hall collection of fossils. This really was a great collection, made by Hall from his own pocket when the State funds proved inadequate for his purposes, and it exceeded in size the State collection itself. A committee of the New York legislature, after investigating Hall's claim to this material, pronounced it valid but declined to buy. As Mr. Whitfield had acquired an intimate acquaintance with the collection through his long service, it seemed to Mr. Bickmore of prime importance that he should go to New York with it, and thus he went in 1877, assuming in the new museum the title and duties of curator of geology, to which was added the custodianship of the collections of recent shells. The new charge that had fallen to Professor Whitfield was a dignified and important one, assuring him reasonable independence of action and a field for individual development, from which conditions at Albany had restrained him. He was influential in establishing the Bulletin of the American Museum, and its early numbers are given up almost exclusively to his scientific papers. Now, as opportunity in the labors of custodianship permitted, he proceeded to carry out his investigations in paleontology into various lines and was the author of many very excellent descriptive papers, brilliantly illuminated by his admirable drawings. Yet I think it is questionable if any scientific work of these years, which he handled independently, will be as enduring as that he had accomplished at Albany under the scrutiny of an older and always critical eye. Yet we must not fail to emphasize the importance of his extensive investigation, published while at the American Museum, of the fauna of the Fort Cassin beds, in which he brought to public notice a Lower Siluric assemblage of fossils exceptional in preservation, in geologic and morphologic interest from a formation—the Beekmantown—of which till that time very little had been learned. And I should add as a specially noteworthy item of his contributions the description of the only known scorpion from the Siluric rocks of this country. His name has entered permanently in the records of his chosen science; twice it has been used as a generic term among the brachiopods, and the species which carry his name as sponsor are legion.

In other directions Professor Whitfield was substantially productive. We have observed that with Hall he was author of reports on the Paleontology of several of the States, and he prepared independent accounts of the invertebrate fossils collected by Federal expeditions and surveys—King's of the Fortieth Parallel, Jenney's and Ludlow's of the Black Hills. For the second Ohio Survey he gave the report on the inverte-

brates, and for the New Jersey Survey prepared his extensive monographs on the Cretaceous fossils.

Personally Professor Whitfield had a pleasing manner, and his long experience with his science and its devotees in this country for more than half a century gave him a fund of reminiscence specially interesting to the younger men. Conscientious in his devotion to his duties, gifted with one of those extraordinary memories for places, dates, details, records and literature which seem to pertain to a distinct category, always careful in safeguarding a never rugged body, he outlived all the contemporaries of his early work, reached the close of his life with comparative freedom from illness and bodily suffering, and left behind a record of permanent achievement and essential progress in his science.

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MEMOIR OF THOMAS CHESMER WESTON [6a]

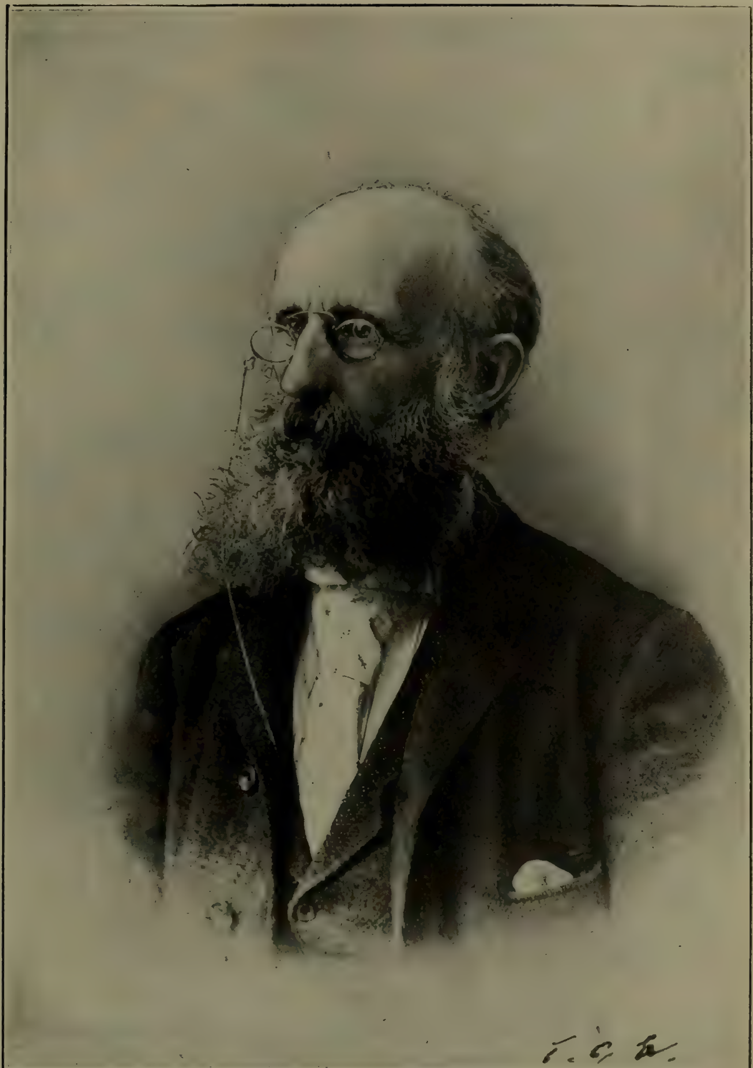
BY ROBERT BELL

Born in Birmingham, England, October, 1832. Arrived in Montreal, and joined the Geological Survey of Canada, 16th February, 1859, æt. 27. Married in Montreal, 9th June, 1859, to Miss Matilda Allen, of Quebec, who predeceased him many years. Superannuated, 1st July, 1894. Died in Minneapolis, 10th May, 1910, æt. 78.

Dr. Bell, with the approval of Miss Weston, writes the following sketch of her late father and of his official career. He had been a friend and associate of Mr. Weston from the day he arrived in Montreal until the time of his death.

Mr. Weston was a man of rather slight or delicate build, fair complexion, with blue eyes, flaxen hair and whiskers, of gentle manners and disposition, even temper, and deliberate in speech. In religion a Protestant. Mr. and Mrs. Weston had three children—Eleanor (Nellie), Chesmer, and George H.—all of whom have survived their parents.

[6a] Contributed after the meeting.



Yours truly
Thos. C. Weston.

The first duties Mr. Weston had to perform on entering the Geological Survey consisted in testing (by cutting and polishing) the characters and adaptability of ornamental and semi-precious stones, of which Canada has a great variety, and it was important to ascertain their uses and values. The non-metallic economic rocks and minerals which he thus brought into notice have added much to our knowledge of the latent wealth of Canada. Another branch of his duties at this period consisted in "developing" fossils, or preparing them for more ready description and illustration. This he did by skillfully filling up breaks, repairing accidents, and by removing rocky matter which covered or obscured them. His delicacy of manipulation allowed him to do this work accurately and artistically.

Mr. Weston's training in England was under his father, and while it gave him a good insight into the art of the jeweler and lapidary, it did not include much of a scientific character. His opportunities on the Geological Survey, however, enabled him to acquire a considerable knowledge of geology, lithology, and microscopy, and he soon showed that he was just the man required to fill the place which he occupied until his retirement, 35 years later.

By going on trips to the field with the more experienced members of the staff, he learned by degrees to do good original work in several branches of geology. The first of these excursions was made with Mr. James Richardson and myself, in 1863, to the Saint Francis River. This was the precursor of many independent journeys occupying from a few weeks to whole seasons, and extending from the coast of Labrador to the Rocky Mountains. In these days the more distant parts of the country were inaccessible except by one's own primitive outfit, until the white man gradually spread into large sections of the regions which were uninhabited when Mr. Weston first set out.

He was particularly expert in collecting fossils, and did much good work in this line in various formations and in widely separated parts of the Dominion. He had a kind of intuitive knowledge as to what beds or what particular spots were likely to yield organic remains, and his quick eye immediately detected anything like a fossil. He thus discovered them in numbers of cases where the rocks had been given up as hopeless from the paleontologists' point of view. He directed his attention to finding new forms or those parts which might be lacking in order to complete a specimen for specific description or illustration. Thus his collections were made judiciously, and they were not burdened with great numbers of duplicates, especially where transportation was expensive or difficult.

Apart from Mr. Weston's usefulness as an explorer, it was found impossible, after his retirement, to procure a successor who, in those branches of his work which were connected with the museum, possessed a similar versatility, mechanical skill, neatness, and deftness, and it soon became evident that the Survey had lost an invaluable member.

Although Mr. Weston had not much practice as an author, his octavo volume of 328 pages, entitled "Reminiscences Among the Rocks," is replete with good descriptions and shows a range of reading which enabled him to make poetical and other quotations whenever they seemed appropriate. His travels in the Northwest Territories took place mostly during the time when the first wanderers of the plains consisted of the waifs and strays, mysterious and odd people with funny notions, who had come from nearly all quarters of the world—a queer lot, many of whom had interesting histories if they could only be known. In connection with his experiences among these pioneers his book contains numerous philosophical reflections, interspersed with humorous stories of what he saw and heard.

His narrative is, however, mainly devoted to his geological operations, which supplement the official accounts of his work as given in the Summary Reports of the Survey for the years he was in these northwestern regions. So rapidly do events follow each other in the wonderful development of these regions that Mr. Weston's book is already useful for historical reference.

The museum work, already referred to in connection with fossils and ornamental stones, together with much desultory field work, mostly among the Quebec rocks, occupied Mr. Weston's time till 1865. In that year he went to Anticosti Island, accompanied by an assistant, and collected fossils along considerable sections of the coast. From that year until the end of his official career he spent the greater part of each season in the field. Until 1873 he often acted as Sir William Logan's assistant or was occupied in museum work; but when time permitted he was off on excursions to various localities, mostly in the province of Quebec.

In 1873 he went to the Labrador coast, accompanied by Mr. C. W. Willimott, who had newly joined the staff, but who remained with us for 35 years, when he was superannuated. They examined the stratified rocks all along the northwest side of the straits of Belisle, and determined their age by means of the fossils they collected.

In 1874, at the request of Mr. Alexander Murray, and with the advice of Sir William Logan, Mr. Weston went to Newfoundland to search for fossils, which no one else could find, in order to determine the age of certain rocks. He was quite successful, having discovered at Mannel's

Brook some species which proved them to be primordial. During the eight years which followed 1874, or till 1882, Weston was occupied with the following and other work:

Study of *Eozoon canadense* and preparation of two fine series of specimens of this form, one for the museum and another for an international exhibition; questions as to the age of certain Quebec rocks; age of formations along the south side of the Lower Saint Lawrence; discovery there of areas of the Utica and Hudson River formations, fossils of the Guelph formation, the upright treelike cylinders in the Potsdam rocks near Kingston; investigations of the older formations of New Brunswick and Nova Scotia; discovery of fossils in various rocks in the eastern townships; also at Bic Harbor and Temiscouata Lake; the geology of Saint Mary and Thessalon rivers and collection of rock specimens from both; discovery of Beatrecia at Stoney Mountain, Man.; collecting fossils at Arisaig, N. S.; making sections of rocks for microscopic study; photographing objects of scientific interest in various parts of the Dominion; removal of the museum from Montreal to Ottawa.

Reports on the results of his field work during the next eleven years, namely 1883-1893 inclusive, in each of which he had a party with him, were prepared by Mr. Weston and are included in the summary reports of the director for these years. In four of these seasons he traversed the country from Red River to the more western plains, and one year entered the foothills of the Rocky Mountains.

In the spring and summer of 1893 he suffered from ill health, but earlier in the year he assisted in preparing the geological collections for the Chicago International Exhibition. This work included everything which required to be done in order to exhibit a fine series of specimens, illustrating all that is known about *Eozoon canadense*, for, although it was no longer considered to be of organic origin, it was still regarded with great interest, and geologists from all parts of the world were gratified by being afforded such a good opportunity of studying it.

In 1894 he was placed on the retired list, at his own request, his superannuation dating from the 1st of July. Having served the government for 35 years, he was allowed the maximum pension. This, together with the income from real estate which he owned in Ottawa and Quebec, enabled him to live comfortably for the remainder of his life, which he spent with the different members of his family and in leisurely traveling in Canada and the United States.

He was fortunate in having innumerable friends and not a single enemy. Sixteen years after his retirement from active work, or at the age of 78 years, he died, on the 10th of May, 1910, at the home of his

daughter in Minneapolis, deeply regretted by every one who had known him.

MEMOIR OF WILLIAM PHIPPS BLAKE[6b]

BY ROSSITER W. RAYMOND

William Phipps Blake was born June 21, 1826, in New York City. His father, Elihu Blake, was a surgeon-dentist of eminence, a direct descendant of William Blake, who settled in the Massachusetts Bay Colony about 1630. He was prepared for college at private schools in New York, and entered the Sheffield School of Yale, where he was graduated as Ph. B. in the chemical course, class of 1852, the first graduating class of the institution. In the same year he became chemist and mineralogist of the New Jersey Zinc Company and chemist of chemical works at Baltimore, Maryland. In 1853 he started the Department of Mineralogy of the World's Fair at New York City. In 1854, 1855, and 1856 he was mineralogist and geologist of the United States Pacific Railroad Surveys of Williamson, Pope, and Whipple and for the War Department at Washington. His writings during this period comprise reports on the geology and mineralogy of California and other parts of the Southwest, and constitute well nigh the earliest scientific accounts of the regions described. One of them was a translation of the Résumé and Field Notes of Jules Marcou, of Whipple's expedition. From 1856 to 1859 he was engaged in explorations of the geology and mineral deposits of North Carolina and other parts of the country. In 1859 he became editor and proprietor of The Mining Magazine, a monthly periodical, founded in 1853 by W. J. Tenny. Blake transferred the publication to New Haven and issued the number for November, 1859, as a "second series" of the original periodical, under the title The Mining Magazine and Journal of Geology, Mineralogy, Metallurgy, Chemistry, and the Arts, in their application to mining and working useful ores and metals, edited by William P. Blake, geologist and mining engineer.

The pages of The Mining Magazine under his editorship contained much information of value and exhibited the promise of an important and influential future, but the time was unpropitious for such an enterprise. The approach of war hindered the further investment of capital in the Southern States, the mineral resources of which Blake had recently explored and was prepared to describe. The Far West was too far away to support, in the absence of railroads, a periodical which could not be cheaply and surely transported to its subscribers. In short, the new series

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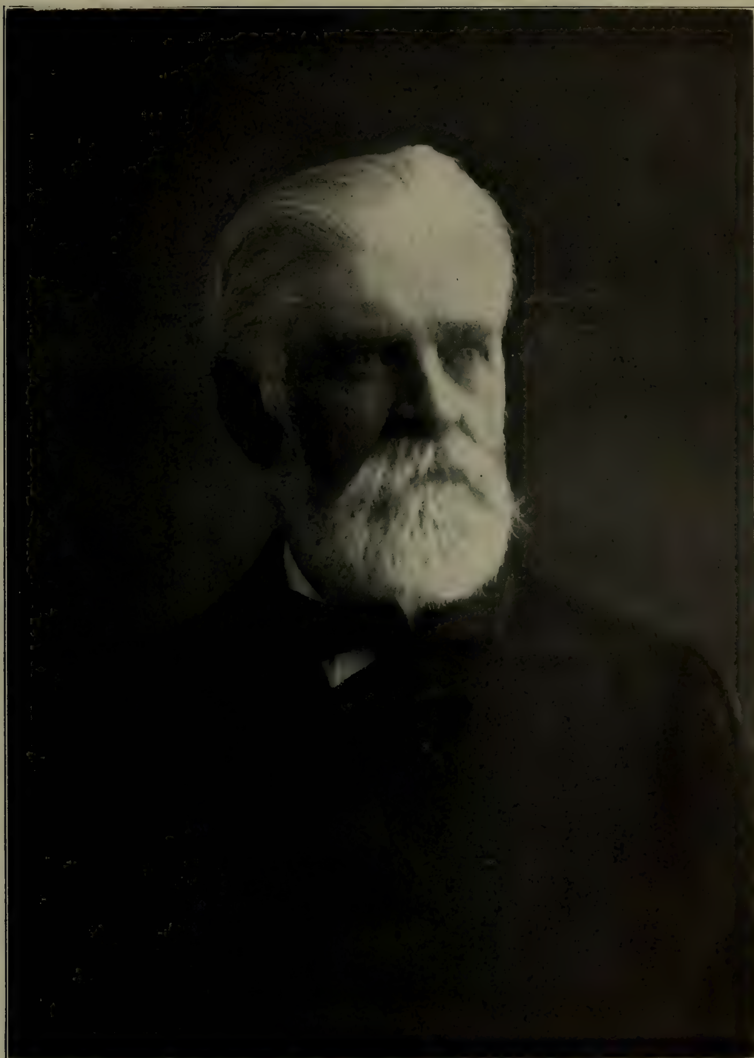
[6b] Condensed by the Secretary, with the author's consent, from the account prepared for the Bulletin of the American Institute of Mining Engineers, No. 45, September, 1910.



Wm P Blake

of The Mining Magazine had to be suspended in 1860, and its editor accepted an engagement which prevented him from reissuing it, namely, that of mining engineer to the Japanese government. This position he occupied from 1861 to 1863. In company with Raphael Pumpelly he organized the first school of science in Japan, and taught chemistry and geology in the school and in the field. He visited China also, returning to the United States by way of Russian America (Alaska). At this time (1863) he explored the Stickeen River, discovered the great Stickeen glacier, and wrote the first description of what was then supposed to be "the ice-mountains." It is said that his reports to Secretary Seward were influential in procuring the consummation of the purchase of Alaska.

Upon his return to California, in 1863, he resumed his work as a field geologist and mining expert, studying especially the character and development of the Comstock lode. In 1864 he was appointed professor of mineralogy and geology in the College of California and also mineralogist of the State Board of Agriculture. In 1867 he was appointed commissioner for California to the Paris Exposition, and was selected by the State Department to edit the Report of the United States Commissioners. This work, which occupied six volumes, occupied him mainly until 1871. In 1871 he was selected chief of the scientific corps of the United States expedition to San Domingo and led his party across that island. In 1873 he was appointed a commissioner of the United States to the Vienna International Exposition, for the report of which he wrote the portion devoted to iron and steel. His efficient service in connection with two international expositions led to his appointment by the Smithsonian Institution in connection with the collection and installation of the United States exhibit of mineral resources at the Centennial Exposition in 1876. This collection formed the nucleus of the Mineral Department of the National Museum at Washington. At the Paris Exposition of 1878 he was again one of the United States commissioners and was appointed secretary of the scientific part of the Commission. Besides editing the report he wrote several of its chapters on ceramics, glass, etcetera.

For the following fifteen years or more Professor Blake was actively and widely engaged as an economic geologist in the exploration of districts and the examination of mines in Arizona, California, Utah, Nevada, Idaho, Montana, and other States and Territories, and published many articles in technical periodicals. A glance at the bibliography appended to this paper will show the extraordinary range of his work. In 1895 he was appointed professor of geology and mining and director of the School of Mines at the University of Arizona, Tucson, Arizona; and although he was already in his seventieth year he engaged in this new

enterprise with all the ardor of youth and prosecuted it with vigor and success for ten years. In 1905 he resigned his position, becoming *professor emeritus.* In January, 1898, he was appointed by the Governor of Arizona territorial mineralogist and geologist, an office to which no salary was attached, but which he accepted with generous public spirit, and the duties of which he discharged until his death twelve years later.

Professor Blake received the honorary degree of M. A. from Dartmouth College in 1863, that of Sc. D. from the University of Pennsylvania in 1906, and that of LL. D. from the University of California in 1910. He was made a chevalier of the Legion of Honor of France in 1878.

It was while in Berkeley, California, attending the semi-centennial anniversary of the University of California that Professor Blake died. For some years past he had been accustomed to spend his winters at Tucson, returning to his home at Mill Rock, New Haven, Connecticut, for the summer months. This year he was invited as one of the earlier professors of the College of California to attend, as the guest of the university, the semi-centennial celebration at Berkeley, and to receive, in recognition of his "distinguished services to geological science," the honorary degree of Doctor of Laws. He left Tucson May 12 (on his return from a geological field examination in Arizona) and reached Berkeley May 14 after a fatiguing journey. Instead of resting he fulfilled with indomitable energy several social engagements already made before yielding to physical weakness and taking to his bed. Even then he could not submit to be treated as an invalid. In spite of the urgent warning of his physician he arose, dressed, and appeared in cap and gown at the Greek theater on Wednesday, May 18, to receive his degree. From this academic triumph he returned to his bed, which he was not to leave again. Pneumonia was rapidly developed, and he died peacefully and in full possession of consciousness early on Sunday morning, May 22, 1910. It was the happy end of a long, honorable, laborious, and useful career.

Professor Blake was preeminently a mining engineer and was a prominent and influential member of the American Institute of Mining Engineers. He joined the institute at its first meeting, in May, 1871, and was elected a vice-president immediately. In 1872, 1873, and 1874 he was unanimously reelected; in 1875 (the new rules, adopted in 1873, having limited the continuous term of a vice-president to two years) he could not be reelected, but in 1876 he was restored to the position of vice-president and served until 1878. Twenty-seven years later, as a veteran of 79, he received once more the honor of a vice-presidency, and I remember well the example of fidelity which he set for younger men by his attendance at the meetings of the Council, to which he came from New Haven.

Professor Blake was a Fellow of the Geological Society of America from 1891 to 1898, when he resigned. He joined again in 1907 and maintained the connection till his death. He was likewise a member or fellow of the American Association for the Advancement of Science, the American Philosophical Society, and the Geological Society of London, and a corresponding member of the Geological Society of Edinburgh.

I first made the acquaintance of Professor Blake in 1868, when I was beginning my work as United States commissioner of mining statistics. In that work I received from him invaluable assistance, and our acquaintance ripened to a friendship which was never broken. In 1873 we were both commissioners to the Vienna Exposition, and after we left Vienna he and his charming wife[6c] joined our party in a journey by carriage through the Bavarian Tyrol. They were ideal traveling companions, merrily superior to all inconveniences of the way, and eagerly appreciative of scenic beauty, historic associations, nature, and human nature.

The portrait accompanying this notice will recall to many friends the striking personal beauty of Professor Blake. His hair turned white while he was still a young man and retained throughout his life its abundant growth, which, together with his noble face, gave to his head almost the aspect of the Phidian Jove. But the clear, ruddy complexion, bright eyes, and genial smile made him too sympathetically human for such a comparison. In conversation he was fascinating, by reason of his own keen interest in what he was saying. He told a fact as if he had only just discovered it. In the art of delivering in "oral abstract" the substance of a technical paper, and illustrating his remarks by rapid blackboard sketches, he had no superior. He did such things with the grace, directness, and lucidity of a generation not pampered with stenographers, typewriters, and lantern slides. Out of our earthly life he has departed—stalwart, versatile, tireless, brave, and gentle to the last—but from my soul, at least, his splendid presence and his serene yet eager spirit will never depart.

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[6c] Professor Blake married, December 25, 1855, Miss Charlotte Haven Lord Hayes, a daughter of William Allen Hayes, of South Berwick, Maine. She died in 1905, at Mill Rock, New Haven, in the fiftieth year of happy wedlock. Of their six children three survive them : Francis H. Blake, Litchfield, Connecticut, and Joseph A. Blake, M. D., and Theodore Whitney Blake, of New York City.

[6d] Arranged chronologically, save for contributions to the chief periodicals and proceedings of learned societies, which are grouped together.

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Provision for the health and comfort of miners—miners' homes. Vol. iii, 1875, pp. 218-221.

The mass copper of the Lake Superior region and the method of mining it. Vol. iv, 1876, pp. 110-111.

Notes on the occurrence of siderite at Gay Head, Massachusetts. Vol. iv, 1876, pp. 112-113.

Note upon the manufacture of ferro-manganese in Austria. Vol. iv, 1876, pp. 216-219.

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Association of apatite with beds of magnetite. Vol. xxi, 1892, pp. 159-160.
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The mineral deposits of southwestern Wisconsin. Vol. xxii, 1894, pp. 558-568.
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Notes on the structure of franklinite and zinc-ore beds, Sussex County, New Jersey. Vol. xxiv, 1895, pp. 521-524.
Alunogen and bauxite of New Mexico. Vol. xxiv, 1895, pp. 571-573.
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Notes and recollections concerning the mineral resources of northern Georgia and western North Carolina. Vol. xxv, 1896, pp. 796-811.
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Notes on the mines and minerals of Guanajuato, Mexico. Vol. xxxii, 1902, pp. 216-223.
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Origin of pebble-covered plains in desert regions. Vol. xxxiv, 1904, pp. 161-162.
Tombstone and its mines. Vol. xxxiv, 1904, pp. 668-670.
Copper ore and garnet in association. Vol. xxxiv, 1904, pp. 886-890.
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MEMOIR OF FRANKLIN R. CARPENTER[1]

BY H. O. HOFMAN

Franklin R. Carpenter was born November 5, 1848, in Parkersburg, West Virginia. When he was less than 4 years old his father died, leaving a widow and three children, of whom Franklin was the eldest. As the widow did not have abundant means, she went about 1853 from Parkersburg to Clarksburg, in Harrison County, to teach in the Broaddus Seminary. Later she became postmistress, her eldest son, at the age of 7 or 8, handling the mail bags. During the Civil War the now 12-year old boy was frequently sent through the lines at Clarksburg with dispatches sewed up in his clothes. In his 14th year he became a "boy" in a Parkersburg hardware store; in his 16th year he was apprenticed to a jeweler and watchmaker. Although skillful at his trade, he was not content to surrender his ambition for a higher education. He read everything that came within his reach. Returning to Clarksburg in 1864, he successfully passed the examination for a teacher's certificate and alternated between school teaching and farm work. In 1865 he studied Latin, mathematics, and natural philosophy, and read much under the guidance of the kindly village physician, Doctor Late, so that he was able to earn a teacher's certificate of the highest grade and to command a better salary.

The survey of the Baltimore and Ohio Railroad in that section formed the turning point in his career by arousing his desire to become a civil engineer. With the money saved while teaching he entered, in 1866, a small denominational school at Pruntytown, West Virginia, called Rector's College, and took the course in civil engineering. His proficiency in mathematics won him the friendship of his teachers. He was graduated in 1868, and had his first engineering experience as rodman with a railroad surveying party at Chillicothe, Ohio. He was quickly advanced to transit man, and after six weeks became chief of the party, but being attacked by malarial fever he returned, in 1869, to West Virginia and became assistant geologist in the State engineer corps. His early experience in laying out railroads doubtless developed the characteristic topographical instinct in geological field work, which enabled him to locate quickly the critical points for observation.

In 1872 he invested his savings in his first financial enterprise by bonding timber and coal lands in West Virginia, but, like most first ventures, this one came to naught and he was obliged to betake himself to school

[1] Condensed by the Secretary, from the Bulletin of the American Institute of Mining Engineers, No. 44, August, 1910.

teaching again, this time at Fetterman, West Virginia. His engagement, in 1873, to Miss Annette Howe, of Athens, Ohio, became the incentive to another westward journey in search of better fortune. He went to Kansas, and later to Denver, Colorado, to make a new start in railroad work. But the panic of 1873 paralyzed all such enterprise, and the young adventurer was reduced to the earning of a bare living by washing gold on Spanish Bar, at Idaho Springs, Colorado. There his character and ability were soon recognized, and he was elected mayor and police judge, and afterwards taught school until the fall of 1874, when he removed to Georgetown, where, receiving the mark of 100 in a competitive examination, he obtained the office of principal of schools. On the strength of this achievement he was married December 23, 1874. In 1876 he was elected county superintendent of schools, and retained this position until 1878, when he opened in Georgetown an office and rapidly built up a good practice as United States deputy surveyor and civil engineer. Two pieces of his engineering work are worthy of record. In 1881 he made for Captain Berthoud the first survey of the "loop," above Georgetown, and in 1882 he located the Loveland Pass tunnel and started work at both portals. In 1882 he took a lease on the Corry City mine, with the intention of driving a cross-cut tunnel to tap the lode, but his financial backing gave out and the scheme had to be abandoned to others, who brought it afterwards to a successful issue.

For a while he returned to his native State—West Virginia—but, having tasted Western freedom and enterprise, he could not be held long in the East. In 1885 he started for British Columbia, but was taken ill in Minnesota and forced to return. In 1886, however, attracted by the new tin deposits of the Black Hills, he went to Rapid City, South Dakota. His leading work that year was the location through the western part of the Black Hills of a railroad line, which is now occupied by a part of the Burlington and Missouri Railroad. At the same time he made geological observations, which were helpful to him later.

In December of the same year he was elected dean of the new Territorial School of Mines, which he opened in 1887, occupying the chair of geology and mining. The Burlington and Missouri Railroad Company recognized his ability and made him its mining engineer, a position which he held until his death. In June, 1887, Ohio University conferred upon him the degree of Master of Arts and in 1888 that of Doctor of Philosophy. In 1889 he became a Fellow of the Geological Society of America and later a Fellow of the American Association for the Advancement of Science. His early reconnoissance of the geology of the Black Hills

prompted the Territorial government to make an appropriation for a geological survey, which was started in 1887 and finished in 1888.

He was a man of kindness of heart, of loyalty to friend and principle, generous to a fault, punctilious when he had charge of other men's affairs, easy going with his own. A striking characteristic was his devotion to wife and family. He lived for his home; the sons found in him their best friend. He was a devout Episcopalian, having become an active member of the church at the early age of 15; his poetic nature made it natural for him to favor the high-church branch of the denomination.

His ideas of right and wrong were well brought out in his management of the Dakota School of Mines. It is an accepted saying that Territorial or State schools pass through a political and a denominational stage before they reach the correst basis for future growth. In the first stage the expenditure of moneys for buildings and apparatus is likely to involve political patronage, and when this period is over and the politicians are no longer actively interested a denominational stage is likely to follow, in which "good men" who have not been successful are provided with berths as "educators." At last the community gets tired of this state of affairs; there is a change of *personnel,* and the institution is set upon the true road to usefulness and success. In 1887 the Dakota School of Mines was in the political stage. The dean had to hold the fort against all open assaults, as well as cunning stratagems, of the politicians. He kept flying, high and unstained, the flag of principle, and never lowered it at any command of interest. What this means can be fully understood perhaps by those only who have gone through a similar experience.

In 1887 I was called to the Dakota School of Mines as professor of metallurgy and assaying. When I was called, in 1889, to another educational institution, and my place was to be filled by the appointment of a successor, whom the dean conscientiously disapproved, he resigned his office without hesitation, although he had at the time no certain prospect of remunerative employment elsewhere.

His genius soon found, however, a new path. He had tested, by crucible experiments in the laboratory, the possibility of melting the siliceous silver-gold ores of Ruby Basin, South Dakota, and had found that this could be done so as to obtain a satisfactory recovery of the precious metals. What remained to be determined was the kind of slag that could be economically produced by this process in a blast furnace. This he undertook to determine at Deadwood in a small blast furnace ("baby smelter"), and when this small operation had proved successful he laid the foundations in mining property and plant for a smelting enterprise on a commercial

scale. In 1891 he erected the Deadwood and Delaware smelter, which by 1898 had grown to comprise five blast furnaces. During this interval he carried on many experiments in semi-pyritic smelting and developed a new mode of operation in this interesting branch of metallurgy. This smelter, destroyed by fire in 1898, was rebuilt by Doctor Carpenter and managed by him until the property changed hands a year or two later.

Domestic afflictions and the impaired health of his wife led him to leave the Black Hills, in 1900, and return to Denver, which remained thereafter his place of residence. His first new work in Colorado was to straighten out the difficulties of the Buena Vista plant; in the same year he designed and built the works of the Rocky Mountain Smelting Company at Florence, and in 1901 he did the same kind of work for the Clear Creek Mining and Reduction Company at Golden, the plant of which he managed until 1903. In 1904 he turned his attention to the electrostatic concentration of the ores of the Nonesuch copper mine at Lake Superior, in which he was successful. But he maintained his general practice as consulting mining engineer in Denver.

His last important problem was the application, in 1908, of the Longmaid-Henderson process to the treatment of Sudbury nickel-copper ores. He showed how by varying the usual mode of operating the copper could be rendered soluble while the nickel remained insoluble, and smelting the residual iron oxide for nickel-bearing pig-iron would furnish a raw material for making nickel steel in the open-hearth furnace.

The same year, 1908, he became a charter member of the Mining and Metallurgical Society of America.

This is, in brief, an outline of the life and career of a man who was always in the front where work was to be done, who by hard work and study prepared himself for the duties that were ahead of him, who had the respect and esteem of all who came into business relations with him, and the personal love of all who knew him intimately.

He leaves a widow, three grown-up sons, who have followed the father's profession, one minor son, and a daughter.

Below is appended a list of his papers. The finished papers are not numerous; the short, signed articles, which he wrote for current newspapers and periodicals to correct erroneous reports or to enlighten popular ignorance, would if collected doubtless amount to several hundred in number.

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The President then called for reports of committees.

REPORT OF THE PHOTOGRAPH COMMITTEE

N. H. Darton, of the Committee on Photographs, reported as follows:

During the past year there has been no change in the collection of photographs belonging to the Society. No new material has been offered and only a few prints have been ordered. It is packed in a chest, which has been recently moved to my new office in the Bureau of Mines, on the northeast corner of G and 8th streets northwest, Washington, D. C. It is conveniently arranged for inspection at any time while I am in the city and prints can be furnished at reasonable rates from negatives in the Geological Survey. A complete catalogue and index of the collection was published several years ago[7] as a bulletin of the Society.

REPORT OF GEOLOGICAL NOMENCLATURE COMMITTEE

For the Committee on Geological Nomenclature, Arthur Keith, as secretary, stated that no calls had been made upon the committee during the year and that it had held no meetings.

AMENDMENT TO THE BY-LAWS

The Secretary then, by instruction of Council, offered the following amendment to paragraph 1, chapter 1, of the By-Laws, three months' notice of the submission of the amendment having been given in print in

[7] Vol. 13, 1902, pp. 377-474.

accordance with the provision of the Constitution: "Add to the last line the word 'fifty' after 'one hundred,' and change the figures in the parentheses accordingly, so that the last clause of the paragraph shall read 'but a single prepayment of one hundred fifty (150) dollars shall be accepted as a commutation for life.'" On motion, the amendment was adopted without dissent.

The Secretary made sundry announcements with reference to the meetings and the provisions for the comfort of the visiting Fellows, and regarding invitations to visit the testing plant of the United States Bureau of Mines and the steel mills in the vicinity of Pittsburgh.

RESOLUTION CONCERNING FREIGHT RATES

By permission from the Society, Mr. W. J. Holland presented the following resolution:

WHEREAS the Geological Society of America desires to represent to the Official Classification Committee, through its chairman, Mr. F. S. Holbrook; to the Western Classification Committee, through its chairman, Mr. F. O. Becker; to the Transcontinental Freight Association, through Mr. R. H. Countiss, and to the Southern Classification Committee, through its chairman, Mr. W. R. Poe, that the present classification of fossils in rock as first-class freight is in their judgment unjust and oppressive; and

WHEREAS the Society admits that to classify fossils after they have been extracted from the rock and mounted as objects of display in museums as first-class freight is not unreasonable, but to assess first-class rates upon masses of rock weighing from fifty to five thousand pounds, being the raw material from which by modern methods fossils are extracted, is in the judgment of the Society illogical and unjust, and that nine-tenths of such blocks are thrown into the dump, and they are, strictly speaking, "raw material," as much so as are the blocks of marble out of which the sculptor carves an image; therefore be it

Resolved, That the Society requests and urges the adoption of the following change in classification: Instead of "fossils in rock, first class," read "fossils extracted from rock and mounted for exhibition, first class; fossils in rock per hundredweight, third class; carload lots, fourth class."

On motion, the resolution was adopted.

The Secretary then submitted the letters which he had received from the foreign Correspondents elected at the Boston-Cambridge meeting, and they were ordered placed on file.

On motion, it was voted that the afternoon session of Wednesday should begin with the reading of the presidential address of Dr. John M. Clarke, retiring President of the Paleontological Society.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

The Society then passed to the reading of papers.

A LIST OF UNDERGROUND TEMPERATURES IN THE UNITED STATES

BY N. H. DARTON

Presented in abstract without manuscript.

MID-CONTINENTAL EOLATION

BY CHARLES R. KEYES

Read by title in the absence of the author.

THE NOMENCLATURE OF FAULTS

BY HARRY FIELDING REID

Read by title in the absence of the author.

THE PROPAGATION OF EARTHQUAKE WAVES

BY HARRY FIELDING REID

Read by title in the absence of the author.

AN UNUSUAL DISTORTION OF THE LOWER KITTANNING COAL

BY RICHARD R. HICE

Presented without manuscript and with lantern slide illustrations.

FURTHER EVIDENCE OF AN UNCONFORMITY IN THE SO-CALLED LARAMIE OF THE RATON COAL FIELD, NEW MEXICO

BY WILLIS THOMAS LEE

Read in part from manuscript and in part presented with the aid of diagrams and lantern slides.

The Society adjourned at 12.40 o'clock for luncheon at the Hotel Schenley. It reconvened at 2.35 o'clock p. m., with Vice-President Schuchert in the chair.

The scientific program was continued as follows:

ON REPEATING PATTERNS IN THE RELIEF AND IN THE STRUCTURE OF THE LAND

BY WILLIAM HERBERT HOBBS

Presented without manuscript; illustrated with lantern slides.

Questions were asked and remarks were made by James F. Kemp and William M. Davis, with reply by W. H. Hobbs.

President Hague resumed the chair.

APPARENT SUN-CRACK STRUCTURE IN DIABASE

BY EDGAR T. WHERRY[8]

Presented without manuscript and with lantern slides. Discussed by G. W. Stose.

GEOLOGY OF PART OF LUNA COUNTY, NEW MEXICO

BY N. H. DARTON

Presented by title at the request of the author.

THE PRE-CAMBRIAN OF SWEDEN, WITH COMMENTS ON AMERICAN TAXONOMIC PARALLELS

BY JAMES J. KEMP

Read in full from manuscript. Discussed by W. G. Miller, H. P. Cushing, and John M. Clarke, with reply by the author.

THE PRE-CAMBRIAN OF SOUTHEASTERN ONTARIO

BY WILLET G. MILLER AND CYRIL W. KNIGHT

Read in full from manuscript by the senior author.

THE SHAWANGUNK GRIT AND ITS FACIAL RELATIONSHIPS

BY GILBERT VAN INGEN

Presented in full without notes, and actively discussed informally after the adjournment of the Society, at 5 o'clock p. m., by W. M. Davis, E. O. Ulrich, H. B. Kümmel, and others.

ADDRESS OF THE RETIRING PRESIDENT

Tuesday evening, at the Hotel Schenley, Dr. Arnold Hague delivered his address as retiring President of the Society, taking as his subject "Origin of the thermal waters in the Yellowstone National Park," which was listened to by an audience of more than a hundred persons. At the close of the address there was held in an adjoining room the smoker, which was given complimentarily by the Carnegie Institute to the Geological Society of America, the Paleontological Society, and the Association of American Geographers.

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[8] Introduced by Benj. L. Miller.

Session of Wednesday, December 28

The Society was called to order at 10.15 o'clock a. m. by President Hague.

On motion, the printed report of the Council was taken from the table and adopted. The report was as follows:

REPORT OF THE COUNCIL

To the Geological Society of America, in Twenty-third Annual Meeting assembled:

The regular annual meeting of the Council was held at Boston and Cambridge, Massachusetts, in connection with the meeting of the Society, December 28 to 31, 1909. An adjourned meeting was held in New York city on February 5, 1910, and some business has been transacted by correspondence.

The details of administration for the twenty-second year of the existence of the Society are given in the following reports of the officers:

Secretary's Report

To the Council of the Geological Society of America:

Meetings.—The proceedings of the annual meeting of the Society held at Boston and Cambridge, Massachusetts, December 28 to 31, 1909, have been recorded in volume 21, pages 1-41, of the Bulletin.

Membership.—During the past year, the Society has lost eight Fellows by death: William Phipps Blake, Franklin R. Carpenter, J. C. K. Laflamme, William H. Niles, David Pearce Penhallow, William G. Tight. T. C. Weston, and Robert Parr Whitfield. Two resignations have become effective. The names of the twenty-four Fellows elected at the Boston-Cambridge meeting have been added to the list, all of them having completed their membership according to rule. The present enrollment of the Society is 319. Eight candidates are before the Society for election, and several applications are under consideration by Council.

Distribution of Bulletin.—In accordance with the announcement made at the last meeting of the Society, the form of publication of the Bulletin was changed to a quarterly issue, beginning with volume 21, and 516 pages have been distributed in the first three parts. Part 4 of the volume, comprising several complete papers, abstracts, discussions, and index, is in the hands of the printer and should be issued by the end of January.

There have been received during the year six new subscriptions to the Bulletin, making the number of subscribers 100. There has been no change in the exchange list. The names of the seven Correspondents

elected at the last meeting of the Society have been added to the mailing list.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, including one complete set, 23; sold to Fellows, 1; sent out to supply deficiencies and delinquents, 6; brochures sent out to supply deficiencies and delinquents, 39; sold to Fellows, 27; sold to the public, 62.

Bulletin Sales.—The receipts from subscriptions to and sales of the Bulletin during the past year are shown in the following table:

Bulletin Sales, December 1, 1909–November 30, 1910

	Complete volumes.			Brochures.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1....	....	$7.50	$7.50	....	....	....	$7.50
Volume 2....	....	7.50	7.50	....	$0.20	$0.20	7.70
Volume 3....	....	7.50	7.50	....	....	....	7.50
Volume 4....	....	7.50	7.50	....	.30	.30	7.80
Volume 5....	....	7.50	7.50	....	.40	.40	7.90
Volume 6....	....	7.50	7.50	....	1.00	1.00	8.50
Volume 7....	....	7.50	7.50	....	....	....	7.50
Volume 8...	....	7.50	7.50	....	.40	.40	7.90
Volume 9....	....	7.50	7.50	....	....	....	7.50
Volume 10....	....	7.50	7 50	$0 10	.80	.90	8.40
Volume 11....	....	7.50	7.50	....	.25	.25	7.75
Volume 12....	....	15.00	15.00	....	....	....	15.00
Volume 13....	....	15.00	15.00	....	....	....	15.00
Volume 14....	....	15.00	15.00	....	2.25	2.25	17.25
Volume 15....	....	15.00	15.00	....	.25	....	15.25
Volume 16....	....	15.00	15.00	1.20	3.90	5.10	20.10
Volume 17....	....	15.00	15.00	....	2.45	....	17.45
Volume 18....	....	15.00	15.00	1.90	.80	2.70	17.70
Volume 19....	$7.50	30.00	37.50	.75	.30	1 05	38.55
Volume 20....	....	142.50	142.50	8.55	23.75	32.30	174.80
Volume 21....	....	622.50	622.50	.50	....	.50	623.00
Volume 22....	....	22.50	22.50	....	....	....	22.50
Total...	$7.50	$1,005.00	$1,012.50	$13.00	$37.05	$42.05	$1,062.55
Index........	....	....	....	....	4.50	4.50	4.50
	$7.50	$1,005.00	$1,012 50	$13 00	$41.55	$46.55	$1,067.05

Receipts for the fiscal year..............................	$1,067.05
Previously reported..	11,245.51
Total receipts to date	$12,312 56
Charged, but not yet received: On 1910 account..........	43.35
Total sales to date	$12,355.91

Thirteen subscriptions to volume 21 are still to be paid for.

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1910

Account of Administration

Postage and telegrams	$39.47	
Express	17.13	
Printing and stationery	182.10	
Engrossing correspondents' certificates	3.50	
Membership fee in International Geological Congress	4.91	
Operator at Boston meeting	10.00	
Expenses of Auditing Committee	4.00	
Paleontological Society	53.00	
Cordilleran Section	28.25	
Total		$342.36

Account of Bulletin

Postage and express	$188.24	
Collection on checks and addressograph plates	4.26	
Reporter of discussions at Boston meeting	25.00	
Purchase of Bulletin	36.30	
Printing and stationery	64.18	
Overpayment and canceled subscription returned	10.00	
Binding	7.00	
Total		334.98
Total expenses for the year		$677.34

Respectfully submitted.

EDMUND OTIS HOVEY,
Secretary.

NEW YORK, *December 12, 1910.*

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending December 1, 1910.

Six (6) Fellows, Arthur L. Day, Charles W. Wright, Charles Palache, W. W. Atwood, E. W. Berry, and Erasmus Haworth, have commuted for life during the year by the payment of one hundred dollars each, thus increasing the total Life Commutations to ninety-nine (99), which with four (4) Honorary Life Members makes a total of one hundred and three (103), of whom ninety-four (94) are now living.

One (1) Fellow is delinquent for four years, one (1) Fellow is delinquent for three years, two (2) Fellows are delinquent for two years and are therefore liable to be dropped from the roll for non-payment of dues, in accordance with section 3, chapter 1 of the By-Laws; fifteen (15) Fellows are delinquent for the present year.

The membership of the Society, including delinquents, aggregates at the present time 319, of whom 94 have commuted for life. There have been eight deaths during the year and two resignations. Twenty-four Fellows were elected at the last meeting, all of whom qualified.

With the advice of the Investment Committee, composed of Messrs. Walcott, Emmons, and the Treasurer *ex officio*, the Treasurer bought during the year a one thousand dollar 4½ per cent. equipment bond of the St. Louis and San Francisco Railroad, at a cost of $970.50.

RECEIPTS

Balance in the treasury December 1, 1909		$1,834.80
Fellowship fees, 1906 (2)	$20.00	
1907 (2)	20.00	
1908 (3)	30.00	
1909 (13)	130.00	
1910 (214)	2,140.00	
1911 (3)	30.00	
		2,370.00
Initiation fees (24)		240.00
Life commutations (6)		600.00
Interest on investments:		
Iowa Apartment House Company	$50.00	
Ontario Apartment House Company	......	
Texas and Pacific Railroad bonds	100.00	
U. S. Steel Corporation bonds	150.00	
St. Louis, Iron Mountain and Southern Railroad bond	50.00	
St. Louis and San Francisco Railroad equipment bond	22.50	
Interest on deposits in Baltimore Trust Company April 1, 1910	42.90	
Interest on deposits in Baltimore Trust Company December 1, 1910	35.81	
		451.21
Case Library		750.00
Collection charges added to checks		.55
Received from Secretary:		
Sales of publications	$1,067.05	
Authors' separates, charges for	129.75	
Authors' corrections, paid by authors	61.78	
Authors' subscription to expense of paper.	71.88	
Refund from express company on account of overcharge	1.05	

Binding two volumes of Bulletin.........	$3.50		
Jurat and collection on check............	.35		
		$1,335.36	
			$7,581.92

EXPENDITURES

Secretary's office:			
Administration	$289.36		
Bulletin	334.98		
Salary	700.00		
Paleontological Society	53.00		
		$1,377.34	
Treasurer's office:			
Postage, bond, stationery, safe deposit, etc.	$51.00		
Allowance for clerical hire..............	50.00		
		101.00	
Library		10.00	
Publication of Bulletin:			
Printing*	$2,738.08		
Engraving	499.11		
Editor's allowance	250.00		
		3,487.19	
Purchase of St. Louis and San Francisco equipment bond		$970.50	
			$5,946.03
Balance in bank December 1, 1910..................................			1,635.89
			$7,581.92

*This item is made up of the following sums:

Printing of Bulletin..............................	$2,563.00	
Authors' separates	113.30	
Authors' corrections in excess of the 5% allowed by the Society (repaid by authors)..................	61.78	
		$2,738.08

Respectfully submitted,

Wm. Bullock Clark,
Treasurer.

Baltimore, Md., *December 1, 1910.*

Editor's Report

To the Council of the Geological Society of America:

In presenting his annual report the Editor desires to avail himself of the opportunity to state that from an editorial standpoint the experience of the past year confirms in large measure the wisdom of the change from an irregular to a regular publication. While there has been some loss in uniformity, there has been gain in efficiency.

In connection with volume 20 attention should be called to the fact that Professor Branner contributed $50 toward the cost of his paper, and the numerous plates used in "Paleogeography of North America" were furnished in part by the author, Professor Schuchert. For volume 21,

Professor H. F. Cleland contributed $71.88 toward the expense of publishing his paper.

The index of the second ten volumes of the Society's publications is completed and the manuscript will be handed the printer early in January.

The following tables cover statistical data for the Society's first twenty volumes:

	Average. Vols. 1–13.	Vol. 14.	Vol. 15.	Vol. 16.	Vol. 17.	Vol. 18.	Vol. 19.	Vol. 20.
	pp. 578. pls. 44.	pp. 609. pls. 65.	pp. 636. pls. 59.	pp. 636. pls. 94.	pp. 785. pls. 84.	pp. 717. pls. 74	pp. 617. pls. 41.	pp. 749. pls. 111.
Letter-press......	$1,580.67	$1,657.50	$1,661 21	$1,817.03	$2,087.98	$2,015.68	$1,591.32	$2,352.25
Illustrations....	339.13	431.21	457.76	706.97	608.68	486.22	289.92	430.53
	$1,919 80	$2,088.71	$2,118.97	$2,524.00	$2,696.66	$2,501.90	$1,881.24	$2,782.78
Average per page..........	$3.33	$3.43	$3.33	$3.96	$3.37	$3.42	$3.00	$3.71

Classification.

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1.......	116	137	92	18	83	44	47	.....	60	4	4	593+xii
2.......	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3.......	56	41	44	41	32	158	104	.....	61	15	1	541+xii
4.......	25	134	38	74	52	52	14	.....	47	32	2	458+xii
5.......	138	135	70	54	28	51	107	.....	71	14	9	665+xii
6.......	50	111	75	39	71	99	1	.....	63	25	4	538+x
7.......	38	77	105	53	40	21	123	4	66	28	13	558+x
8.......	34	50	98	5	43	67	58	14	79	8	....	446+x
9.......	2	102	138	.....	44	28	64	16	64	12	....	460+x
10.......	35	33	96	37	59	62	68	28	84	27	17	534+xii
11.......	65	110	21	10	54	31	188	7	71	60	46	651+xii
12.......	199	39	55	53	24	98	5	5	70	2	....	538+xii
13.......	125	17	13	24	28	116	42	4	165	32	29	583+xii
14.......	48	47	48	59	183	118	22	1	80	14	1	609+xii
15	26	124	3	94	36	267	.....	.....	77	17	3	636+x
16.......	64	111	78	30	102	141	19	.....	67	22	15	636+xii
17.......	49	161	41	84	47	294	27	.....	71	9	2	785+xiv
18.......	16	164	141	5	29	246	5	.....	68	40	3	717+xii
19.......	106	108	29	66	30	155	32	.....	56	15	20	617+x
20.......	43	54	35	29	37	45	303	8	60	3	132	749+xiv

Respectfully submitted. JOSEPH STANLEY-BROWN,
Editor.

COLD SPRING HARBOR, N. Y., *December 15, 1910.*

REPORT OF THE AUDITING COMMITTEE

The Auditing Committee, through its chairman, James F. Kemp, then presented its report to the effect that the committee had examined the Treasurer's accounts and had found them properly cast and correctly vouched. On motion, the report was adopted.[9]

The Secretary then read the following resolution, which had been approved by Council at a meeting on Tuesday, for recommendation to the Society:

RESOLUTION CONCERNING CANADIAN FORESTRY SCHOOL

It is the sense of the Council and Fellows (both Canadian and American) of the Geological Society of America, in session assembled December 28, 1910, that the proposal of the friends and compatriots of their lamented member and Fellow, the late Monseigneur Laflamme, to the effect that the School of Forestry recently established in and by the province of Quebec and at the University of Laval, which was the platform of his long and influential career in science, should bear his name as a tribute to his efficiency and devotion, is befitting and felicitous, and it is the further sense of this Council and Fellowship that this formal expression may appropriately be transmitted by the Secretary to the premier of the province of Quebec and the rector of Laval University.

On motion, this resolution was unanimously adopted.

REPORT OF DELEGATES TO THE INTERNATIONAL GEOLOGICAL CONGRESS

James F. Kemp then presented an oral report, briefly summarizing the reception of the delegates of the Society to the Eleventh International Geological Congress, held at Stockholm in the summer of 1910.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

The scientific program was resumed as follows:

THE CHAZY FORMATION IN THE OTTAWA VALLEY

BY PERCY E. RAYMOND

Read in full from manuscript. Discussed by H. P. Cushing.

PROPOSED MODIFICATIONS IN THE NOMENCLATURE OF THE EARLY PALEOZOIC ROCKS OF NEW YORK

BY H. P. CUSHING

Read in full from manuscript. Discussed by C. S. Prosser and E. O. Ulrich.

[9] S. F. Emmons reports having visited Baltimore on January 25, 1911, and found the securities in the possession of the Treasurer to correspond with the list reported by him.

THE FRANKFORT AND UTICA SHALES OF THE MOHAWK VALLEY

BY RUDOLF RUEDEMANN

Read by title in the absence of the author.

THE STRATIGRAPHY OF THE LOWER PENNSYLVANIAN OF NORTHEASTERN OKLAHOMA

BY D. W. OHERN[10]

Presented without manuscript. Discussed by C. S. Prosser, with reply by the author.

SKETCH OF THE LOCAL GEOLOGY, CITY OF PITTSBURGH

BY PERCY E. RAYMOND

Presented without manuscript; illustrated with lantern slides. Discussed by E. W. Shaw.

THE CRETACEOUS AND TERTIARY FORMATIONS OF WESTERN NORTH DAKOTA AND EASTERN MONTANA

BY A. G. LEONARD

Read by title in the absence of the author.

EOCENE AND OLIGOCENE OF THE WIND RIVER AND BIG HORN BASINS

BY WILLIAM J. SINCLAIR AND WALTER GRANGER

Read in full from manuscript by the senior author, with lantern slide illustrations. Discussed by Marius R. Campbell, with reply by W. J. Sinclair.

The Society adjourned at 12.50 o'clock, and was called to order again by the President at 2.20 o'clock p. m., when John M. Clarke, by invitation of the Society, delivered his address as retiring President of the Paleontological Society, entitled "The paleontologist and the public, the paleontology of right living."

The Geological Society of America then resumed its scientific program, former President Samuel Calvin being in the chair.

REVISION OF THE PALEOZOIC SYSTEM OF NORTH AMERICA. PART II

BY EDWARD O. ULRICH

Presented in abstract from the complete manuscript.

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[10] Introduced by C. N. Gould.

On account of the length of the program, the Society voted to divide the meeting into two sections, continuing the glacial and physiographic papers in the main room and transferring the presentation of the petrologic, mineralogic, and economic papers to a room in the Carnegie Technical School for Wednesday morning.

The following papers were then presented:

THE TWENTY-FOOT TERRACE AND SEA-CLIFF OF THE LOWER SAINT LAWRENCE

BY JAMES WALTER GOLDTHWAIT

Given in abstract from notes. Discussed by F. B. Taylor, with reply by the author.

IROQUOIS AND INFERIOR WATERS IN NORTHERN NEW YORK

BY H. L. FAIRCHILD AND G. H. CHADWICK

Presented by the senior author without notes and discussed by A. P. Coleman.

PRE-GLACIAL COURSE OF THE UPPER HUDSON RIVER

BY WILLIAM J. MILLER

Presented without manuscript and discussed by James F. Kemp and H. L. Fairchild, with reply by the author.

THE MOHAWK GLACIAL LOBE

BY ALBERT PERRY BRIGHAM

Presented without manuscript and discussed by H. L. Fairchild and Lawrence Martin, with reply by the author.

Adjournment was taken at 5.40 o'clock p. m.

ANNUAL DINNER

The annual dinner of the Society was held Wednesday evening at the Hotel Schenley, with President Hague in charge. At the close of the dinner the President delivered a brief address, introducing W. J. Holland, as the representative of the hosts of the meeting, and William M. Davis, the incoming President. He then surrendered the chair to James F. Kemp, who acted as toastmaster, and in the course of the evening called upon the following Fellows for remarks: J. M. Clarke, W. N. Rice, L. G. Westgate, Collier Cobb, A. H. Purdue, A. P. Coleman, and H. L. Fairchild.

Session of Thursday, December 29

The meeting of the Glacial and Physiographic Section was called to order at 9.30 o'clock a. m. in the Carnegie Museum, with former President Samuel Calvin in the chair and C. P. Berkey acting as secretary *pro tempore.*

PROGRAM OF THE GLACIAL AND PHYSIOGRAPHIC SECTION

The program of the Section was taken up as follows:

LAKE MAUMEE, IN OHIO

BY FRANK CARNEY

Presented without manuscript. Discussed by F. B. Taylor.

A STUDY OF ICE-SHEET EROSION AND DEPOSITION IN THE REGION OF THE GREAT LAKES

BY FRANK BURSLEY TAYLOR

Presented without manuscript and illustrated with maps. Discussed by C. A. Davis, R. D. Salisbury, and J. B. Tyrrell.

THE IOWAN DRIFT

BY SAMUEL CALVIN

Read in full from manuscript.

THE PLEISTOCENE OF THE VICINITY OF SIOUX FALLS, SOUTH DAKOTA

BY B. SHIMEK

Read by title in the absence of the author.

THE PLEISTOCENE OF THE VICINITY OF OMAHA, NEBRASKA, AND COUNCIL BLUFFS, IOWA

BY B. SHIMEK

Read by title in the absence of the author.

THE LESSONS OF THE LITTLE YOSEMITE VALLEY

BY F. E. MATTHES[11]

Read by title in the absence of the author.

[11] Introduced by W. H. Hobbs.

TWO GLACIERS IN ALASKA

BY LAWRENCE MARTIN

Presented in abstract from notes, with lantern slides. Discussed by R. S. Tarr and A. H. Brooks, with reply by the author.

A SYSTEM OF QUATERNARY LAKES IN THE MISSISSIPPI BASIN

BY E. B. SHAW[12]

Read in full from manuscript and illustrated with diagrams. Discussed by W. M. Davis, F. B. Taylor, and R. D. Salisbury, with reply by the author.

AFTONIAN MAMMALIAN FAUNA II

BY SAMUEL CALVIN

Presented in abstract from notes.

E. O. Hovey returned from the other section and resumed his duties as secretary.

RADIATION OF GLACIAL FLOW AS A FACTOR IN DRUMLIN FORMATION

BY WILLIAM C. ALDEN

Read in full from manuscript and illustrated with charts. Discussed by H. L. Fairchild.

NOTES ON A NEW METHOD OF CALCULATING THE DATE OF THE GLACIAL EPOCH

BY RUFUS M. BAGG, JR.

Read by title in the absence of the author.

PHYSIOGRAPHIC STUDIES IN THE SAN JUAN DISTRICT OF COLORADO

BY WALLACE W. ATWOOD

Presented without manuscript and illustrated with diagrams. Discussed by W. M. Davis and F. W. Rich.

GEOGRAPHICAL DESCRIPTIONS IN THE FOLIOS OF THE GEOLOGIC ATLAS OF THE UNITED STATES

BY W. M. DAVIS

Read by title at the request of the author.

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[12] Introduced by David White.

PROGRAM OF THE PETROLOGIC, MINERALOGIC, AND ECONOMIC SECTION

The Petrologic, Mineralogic, and Economic Section organized in one of the recitation-rooms of the Carnegie Technical School, with H. B. Patton as chairman and E. O. Hovey as secretary.

The following papers were presented:

QUANTITATIVE CLASSIFICATION OF METEORITES

BY OLIVER C. FARRINGTON

Given in abstract without notes, with the aid of lantern slides, and discussed by E. O. Hovey and the author.

THE MOLDAVITE QUESTION

BY GEORGE P. MERRILL

Read by title in the absence of the author.

THE GEM-BEARING PEGMATITES OF THE WORLD

BY GEORGE F. KUNZ

Read by title in the absence of the author.

THE CLINTON SAND AS A SOURCE OF OIL IN OHIO

BY J. A. BOWNOCKER

Presented without manuscript. Discussed by F. G. Clapp and O. C. Farrington, with reply by the author.

NOTES ON THE GEOLOGICAL RELATIONS OF OIL POOLS SITUATED IN REGIONS OF MONOCLINAL STRUCTURE

BY FREDERICK G. CLAPP

Read in full from manuscript, with lantern slide illustrations. Discussed by C. W. Washburn, with reply by the author.

THE GEOLOGY OF THE CHIBOUGAMAN REGION, QUEBEC, CANADA

BY ALFRED ERNEST BARLOW

Read by title in the absence of the author.

THE OCCURRENCE OF SILVER, COPPER, AND LEAD ORES AT THE VETA RICA MINE, SIERRA MOJADA, COAHUILA, MEXICO

BY FRANK R. VAN HORN

Presented without notes and illustrated with lantern slides and specimens.

Adjournment to the main section was taken at 12 o'clock.

At the close of the reading of papers the Society passed a most cordial vote of thanks to the Board of Trustees of the Carnegie Institute for the ample and convenient accommodations that had been provided for the meetings and for the many courtesies which had been extended, including the complimentary smoker and the printing of the programs. Special mention was made of Dr. W. J. Holland, Director of the Museum, for the completeness of the arrangements for the actual sessions of the Society.

The attendance at the meeting was large and satisfactory, especially when the small number of geologists resident in and near Pittsburgh is taken into consideration. Ninety-five Fellows and four Fellows-elect signed the register or were noted as being in attendance. The list is as follows:

Register of the Pittsburgh Meeting, 1910

FELLOWS

William Clinton Alden
George Hall Ashley
Wallace Walter Atwood
Alfred Ernest Barlow
Ray Smith Bassler
William S. Bayley
Charles P. Berkey
Samuel Walker Beyer
John Adams Bownocker
Albert Perry Brigham
Reginald W. Brock
Alfred Hulse Brooks
Henry Andrew Buehler
Fred Harvey Hall Calhoun
Samuel Calvin
Marius R. Campbell
Frank Carney
Frederick G. Clapp
William Bullock Clark
John Mason Clarke
Collier Cobb
Arthur P. Coleman
William O. Crosby
Henry P. Cushing
Reginald A. Daly
Nelson H. Darton
William M. Davis
Edward V. d'Invilliers
Richard E. Dodge
John Alexander Dresser
Charles R. Eastman
Herman L. Fairchild
Oliver C. Farrington
Nevin M. Fenneman
August F. Foerste
James Walter Goldthwait
Charles Newton Gould
Arnold Hague
Baird Halberstadt
Richard R. Hice
William Herbert Hobbs
Joseph A. Holmes
Thomas C. Hopkins
Edmund Otis Hovey
Mark S. W. Jefferson
Arthur Keith
James F. Kemp
Frank H. Knowlton
Henry B. Kümmel
Willis Thomas Lee
Joseph Volney Lewis
James Rieman Macfarlane
Curtis F. Marbut
George Curtis Martin
Lawrence Martin
Edward B. Mathews
Samuel Washington McCallie
Arthur M. Miller
Benjamin L. Miller
Willet G. Miller
William John Miller
William A. Parks
Horace B. Patton
Frederick B. Peck
Richard A. F. Penrose
Charles S. Prosser
Albert Homer Purdue
Percy Edward Raymond
William North Rice
Charles H. Richardson
Heinrich Ries
Rudolph Ruedemann

Rollin D. Salisbury
Charles Schuchert
William John Sinclair
Eugene A. Smith
Philip S. Smith
Timothy William Stanton
George Willis Stose
Ralph S. Tarr
Frank B. Taylor
Joseph B. Tyrrell
Edward O. Ulrich
Frank Robertson Van Horn
Gilbert van Ingen
M. Edward Wadsworth
Charles D. Walcott
Thomas L. Watson
Stuart Weller
Lewis G. Westgate
David White
Israel C. White
Ira A. Williams
Samuel W. Williston
Alfred W. G. Wilson

FELLOWS-ELECT

Charles Albert Davis
William Jacob Holland
Olaf August Peterson
George Reber Wieland

OFFICERS, CORRESPONDENTS, AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1911

President:

William M. Davis, Cambridge, Mass.

Vice-Presidents:

William North Rice, Middletown, Conn.
William B. Scott, Princeton, N. J.

Secretary:

Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.

Treasurer:

Wm. Bullock Clark, Baltimore, Maryland

Editor:

J. Stanley-Brown, Cold Spring Harbor, Long Island, N. Y.

Librarian:

H. P. Cushing, Cleveland, Ohio

Councilors:

(Term expires 1911)

Geo. Otis Smith, Washington, D. C.
Henry S. Washington, Locust, New Jersey

(Term expires 1912)

J. B. Woodworth, Cambridge, Mass.
C. S. Prosser, Columbus, Ohio

(Term expires 1913)

A. H. Purdue, Fayetteville, Ark.
Heinrich Ries, Ithaca, N. Y.

MEMBERSHIP, 1911

CORRESPONDENTS

Charles Barrois, D. ès Sc., D. Sc., Lille, France. Professor of Geology at the University. December, 1909.

W. C. Brögger, Sc. D., LL. D., Christiania, Norway. Professor of Geology and Mineralogy at the Royal University. December, 1909.

Giovanni Capellini, Bologna, Italy. Professor of Geology at the University. December, 1910.

Baron Gerhard De Geer, Ph. D., Stockholm, Sweden. Professor of Geology at the University. December, 1910.

Sir Archibald Geikie, D. C. L., Sc. D., LL. D., Hasslemere, England. President of the Royal Society, late Director General of the Geological Survey of the United Kingdom. December, 1909.

Albert Heim, D. Sc., Zürich, Switzerland. President of the Swiss Geological Commission and Professor of Geology at the University. December, 1909.

Emanuel Kayser, Ph. D., Marburg, Germany. Professor of Geology at the University. December, 1909.

A. Michel-Levy, Paris, France. Director of the Geological Survey of France. December, 1910.

H. Rosenbusch, Ph. D., Heidelberg, Germany. Geheimer Rath, Professor (retired) of Geology at Heidelberg University. December, 1910.

Eduard Suess, Ph. D., Vienna, Austria. Formerly Professor of Geology at the Imperial Royal University, President of the Imperial Academy of Sciences. December, 1909.

Emil Tietze, Ph. D., Vienna, Austria. Ober-Bergrath, Director of the Imperial-Royal Geological Survey. December, 1910.

Th. Tscherischew, Ph. D., St. Petersburg, Russia. Director of the Imperial Geological Survey. December, 1910.

Ferdinand Zirkel, D. Sc., Ph. D., Königstrasse 27, Bonn, Germany. Geheimer Rath, Professor (retired) of Mineralogy and Geology at the University of Leipzig. December, 1909.

FELLOWS

*Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., Ph. D., U. S. Weather Bureau, Washington, D. C. August, 1899.

Frank Dawson Adams, Ph. D., McGill University, Montreal, Canada. December, 1889.

George I. Adams, Sc. D., Bureau of Mines, Manila, P. I. December, 1902.

José Guadalupe Aguilera, Ph. D., Instituto Geologico, Mexico, Mexico. August, 1896.

William Clinton Alden, A. B., A. M., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1909.

Truman H. Aldrich, M. E., 1739 P St. N. W., Washington, D. C. May, 1889.

Henry M. Ami, A. M., Geological and Natural History Survey of Canada, Ottawa, Canada. December, 1889.

Frank M. Anderson, B. A., M. S., State Mining Bureau, 2604 Ætna Street, Berkeley, Cal. June, 1902.

Philip Argall, 728 Majestic Building, Denver, Colo. August, 1896.

Ralph Arnold, Ph. D., 726 H. W. Hellman Bldg., Los Angeles, Cal. December, 1904.

George Hall Ashley, M. E., Ph. D., Capitol Annex, Nashville, Tenn. August, 1895.

Wallace Walter Atwood, B. S., Ph. D., University of Chicago, Chicago, Ill. December, 1909.

Rufus Mather Bagg, Jr., Ph. D., University of Illinois, Urbana, Ill. December, 1896.

Harry Foster Bain, M. S., 667 Howard St., San Francisco, Cal. December, 1895.

S. Prentiss Baldwin, 736 Prospect St., Cleveland, Ohio. August, 1895.

Sydney H. Ball, A. B., 71 Broadway, New York City. December, 1905.

Erwin Hinckley Barbour, Ph. D., University of Nebraska, Lincoln, Neb. December, 1896.

Alfred Ernest Barlow, B. A., M. A., D. Sc., 328 Roslyn Ave., Westmont, Montreal, Canada. December, 1906.

Joseph Barrell, Ph. D., Yale University, New Haven, Conn. December, 1902.

George H. Barton, B. S., Boston Society of Natural History, Boston, Mass. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr College, Bryn Mawr, Pa. August, 1894.

Ray Smith Bassler, B. A., M. S., Ph. D., U. S. National Museum, Washington, D. C. December, 1906.

Edson Sunderland Bastin, A. B., A. M., A. S., Geological Survey, Washington, D. C. December, 1909.

William S. Bayley, Ph. D., University of Illinois, Urbana, Ill. December, 1888.

*George F. Becker, Ph. D., U. S. Geological Survey, Washington, D. C.

Joshua W. Beede, Ph. D., Indiana University, Bloomington, Ind. December, 1902.

Robert Bell, I. S. O., Sc. D., M. D., LL. D., F. R. S., Geological Survey, Department of Mines, Ottawa, Canada. May, 1889.

Charles P. Berkey, Ph. D., Columbia University, New York, N. Y. Aug., 1901.

Edward Wilber Berry, Johns Hopkins University, Baltimore, Md. December, 1909.

Samuel Walker Beyer, Ph. D., Iowa Agricultural College, Ames, Iowa. December, 1896.

Arthur B. Bibbins, Ph. B., Woman's College, Baltimore, Md. December, 1903.

Albert S. Bickmore, Ph. D., 64th St. and Central Park West, New York, N. Y. December, 1889.

Elliott Blackwelder, A. B., University of Wisconsin, Madison, Wis. December, 1908.

Willis Stanley Blatchley, A. B., A. M., State House, Indianapolis, Ind. December, 1909.

John M. Boutwell, M. S., U. S. Geological Survey, Washington, D. C. December, 1905.

John Adams Bownocker, D. Sc., Ohio State University, Columbus, Ohio. December, 1904.

*John C. Branner, Ph. D., Leland Stanford, Jr., University, Stanford University, Cal.

Albert Perry Brigham, A. B., A. M., Colgate University, Hamilton, N. Y. December, 1893.

Reginald W. Brock, M. A., Geological Survey, Department of Mines, Ottawa, Canada. December, 1904.

Alfred Hulse Brooks, B. S., U. S. Geological Survey, Washington, D. C. August, 1899.

Amos P. Brown, Ph. D., University of Pennsylvania, Philadelphia, Pa. December, 1905.

Barnum Brown, A. B., American Museum of Natural History, New York, N. Y. December, 1910.

Charles Wilson Brown, Ph. B., A. M., Brown University, Providence, R. I. December, 1908.

Ernest Robertson Buckley, Ph. D., Rolla, Mo. June, 1902.

Henry Andrew Buehler, B. S., Rolla, Mo. December, 1909.

Fred Harvey Hall Calhoun, B. S., Ph. D., Clemson College, S. C. December, 1909.

*Samuel Calvin, Ph. D., LL. D., State University of Iowa, Iowa City, Iowa.

Henry Donald Campbell, Ph. D., Washington and Lee University, Lexington, Va. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Frank Carney, A. B., Denison University, Granville, Ohio. December, 1908.

Ermine C. Case, Ph. D., University of Michigan, Ann Arbor, Mich. December, 1901.

*T. C. Chamberlin, LL. D., University of Chicago, Chicago, Ill.

Clarence Raymond Claghorn, B. S., M. E., Tacoma, Wash. August, 1891.

Frederick G. Clapp, S. B., 610 Fitzsimmons Bldg., Pittsburgh, Pa. Dec., 1905.

*William Bullock Clark, Ph. D., Johns Hopkins University, Baltimore, Md.

John Mason Clarke, A. M., Ph. D., Albany, N. Y. December, 1897.

Herdman F. Cleland, Ph. D., Williams College, Williamstown, Mass. December, 1905.

J. Morgan Clements, Ph. D., Room 1707, 42 Broadway, New York City. December, 1894.

Collier Cobb, A. B., A. M., University of North Carolina, Chapel Hill, N. C. December, 1894.

Arthur P. Coleman, Ph. D., Toronto University, Toronto, Canada. Dec., 1896.

George L. Collie, Ph. D., Beloit College, Beloit, Wis. December, 1897.

Arthur J. Collier, A. M., S. B., U. S. Geological Survey, Washington, D. C. June, 1902.

*Theodore B. Comstock, Sc. D., Los Angeles, Cal.

Eugene Coste, B. ès Sc., E. H., Toronto, Canada. December, 1906.

*Francis W. Cragin, Ph. D., Colorado College, Colorado Springs, Colo.

Alja Robinson Crook, Ph. D., State Museum of Natural History, Springfield, Ill. December, 1898.

*William O. Crosby, B. S., Massachusetts Institute of Technology, Boston, Mass.

Whitman Cross, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Garry E. Culver, A. M., 1104 Wisconsin St., Stevens Point, Wis. Dec., 1891.

Edgar R. Cumings, Ph. D., Indiana University, Bloomington, Ind. August, 1901.

*Henry P. Cushing, M. S., Ph. D., Western Reserve University, Adelbert College, Cleveland Ohio.

Reginald A. Daly, Ph. D., Massachusetts Institute of Technology, Boston, Mass. December, 1905.

Edward Salisbury Dana, A. B., A. M., Ph. D., Yale University, New Haven, Conn. December, 1908.

*Nelson H. Darton, U. S. Bureau of Mines, Washington, D. C.

Charles Albert Davis, A. B., A. M., Ph. D., U. S. Bureau of Mines, Washington, D. C. December, 1910.

*William M. Davis, S. B., M. E., Harvard University, Cambridge, Mass.

Arthur Louis Day, B. A., Ph. D., Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1909.

David T. Day, Ph. D., U. S. Geological Survey, Washington, D. C. Aug., 1891.

Bashford Dean, A. B., A. M., Ph. D., Columbia University, New York, N. Y. December, 1910.

Orville A. Derby, M. S., No. 80 Rua Visconde do Rio Branco, Sao Paulo, Brazil. December, 1890.

Frank Wilbridge De Wolf, B. S., Urbana, Ill. December, 1909.

*Joseph S. Diller, B. S., U. S. Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 506 Walnut St., Philadelphia, Pa. Dec., 1888.

Richard E. Dodge, A. M., Teachers' College, New York, N. Y. August, 1897.

Noah Fields Drake, Ph. D., Imperial Tientsin University, Tientsin, China. December, 1898.

John Alexander Dresser, B. A., M. A., Geological Survey of Canada, Ottawa, Ontario, Canada. December, 1906.

Charles R. Dryer, M. A., M. D., Indiana State Normal School, Terre Haute, Ind. August, 1897.

*Edwin T. Dumble, 1306 Main St., Houston, Texas.

Clarence Edward Dutton, A. B., Englewood, N. J. December, 1907.

Arthur S. Eakle, Ph. D., University of California, Berkeley, Cal. Dec., 1899.

Charles R. Eastman, A. M., Ph. D., Museum of Comparative Zoology, Harvard University, Cambridge, Mass. December, 1895.

Edwin C. Eckel, B. S., C. E., Munsey Building, Washington, D. C. Dec., 1905.

Arthur H. Elftman, Ph. D., P. O. Box 601, Tonopah, Nevada. Dec., 1898.

*Benjamin K. Emerson, Ph. D., Amherst College, Amherst, Mass.

*Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington, D. C.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., State Mining Bureau, Berkeley, Cal. August, 1892.

*Herman L. Fairchild, B. S., University of Rochester, Rochester, N. Y.

Oliver C. Farrington, Ph. D., Field Museum of Natural History, Chicago, Ill. December, 1895.

Nevin M. Fenneman, Ph. D., University of Cincinnati, Cincinnati, Ohio. December, 1904.

Cassius Asa Fisher, A. B., A. M., 711 Ideal Bldg., Denver, Colo. Dec., 1908.

August F. Foerste, Ph. D., Steele High School, Dayton, Ohio. Dec., 1899.

William M. Fontaine, A. M., University of Virginia, Charlottesville, Va. December, 1888.

Myron Leslie Fuller, S. B., 104 Belmont Ave., Brockton, Mass. Dec., 1898.

Henry Stewart Gane, Ph. D., Santa Barbara, Cal. December, 1896.

Russell D. George, A. B., A. M., University of Colorado, Boulder, Colo. December, 1906.

*Grove K. Gilbert, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

Adam Capen Gill, Ph. D., Cornell University, Ithaca, N. Y. December, 1888.

L. C. Glenn, Ph. D., Vanderbilt University, Nashville, Tenn. June, 1900.

James Walter Goldthwait, A. B., A. M., Ph. D., Dartmouth College, Hanover, N. H. December, 1909.

Charles H. Gordon, Ph. D., University of Tennessee, Knoxville, Tenn. August, 1893.

Charles Newton Gould, A. M., University of Oklahoma, Norman, Okla. December, 1904.

Amadeus W. Grabau, S. M., S. D., Columbia University, New York, N. Y. December, 1898.

Ulysses Sherman Grant, Ph. D., Northwestern University, Evanston, Ill. December, 1890.

Herbert E. Gregory, Ph. D., Yale University, New Haven, Conn. Aug., 1901.

George P. Grimsley, Ph. D., Geological Survey of West Virginia, Martinsburg, W. Va. August, 1895.

Leon S. Griswold, A. B., Plymouth, Mass. August, 1902.

Frederic P. Gulliver, Ph. D., Norwichtown, Conn. August, 1895.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

Baird Halberstadt, Pottsville, Pa. December, 1909.

*Christopher W. Hall, A. M., University of Minnesota, Minneapolis, Minn.

Gilbert D. Harris, Ph. B., Cornell University, Ithaca, N. Y. December, 1903.

John Burchmore Harrison, M. A., F. I. C., F. G. S., Georgetown, British Guiana. June, 1902.

John B. Hastings, M. E., 1480 High St., Denver, Colo. May, 1889.

*Erasmus Haworth, Ph. D., University of Kansas, Lawrence, Kans.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Oscar H. Hershey, Kellogg, Idaho. December, 1909.

Richard R. Hice, B. S., Beaver, Pa. December, 1903.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., 25 Broad St., New York, N. Y.

Richard C. Hills, Denver, Colo. August, 1894.

*Charles H. Hitchcock, Ph. D., LL. D., Honolulu, Hawaiian Islands.

William Herbert Hobbs, Ph. D., University of Michigan, Ann Arbor, Mich. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York, N. Y.

William Jacob Holland, A. B., A. M., Carnegie Museum, Pittsburgh, Pa. December, 1910.

Arthur Hollick, Ph. D., New York Botanical Garden, Bronx Park, New York City. August, 1893.

*Joseph A. Holmes, U. S. Geological Survey, Washington, D. C.

Thomas C. Hopkins, Ph. D., Syracuse University, Syracuse, N. Y. Dec., 1894.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York, N. Y.

*Horace C. Hovey, D. D., Newburyport, Mass.

Ernest Howe, Ph. D., 75 Kay St., Newport, R. I. December, 1903.

*Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

Ellsworth Huntington, A. B., A. M., Yale University, New Haven, Conn. December, 1906.

Louis Hussakof, B. S., Ph. D., American Museum of Natural History, New York, N. Y. December, 1910.

Joseph P. Iddings, Ph. B., University of Chicago, Chicago, Ill. May, 1889.

John D. Irving, Ph. D., Yale University, New Haven, Conn. December, 1905.

A. Wendell Jackson, Ph. B., 432 Saint Nicholas Ave., New York, N. Y. December, 1888.

Robert T. Jackson, S. D., Harvard University, Cambridge, Mass. Aug., 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

Thomas Augustus Jaggar, Jr., A. B., A. M., Ph. D., Massachusetts Institute of Technology, Boston, Mass. December, 1906.

Mark S. W. Jefferson, A. M., Michigan State Normal College, Ypsilanti, Mich. December, 1904.

Albert Johannsen, B. S., Ph. D., University of Chicago, Chicago, Ill. December, 1908.

Douglas Wilson Johnson, B. S., Ph. D., Harvard University, Cambridge, Mass. December, 1906.

Alexis A. Julien, Ph. D., Columbia University, New York, N. Y. May, 1889.

George Frederick Kay, M. A., State University of Iowa, Iowa City, Iowa. December, 1908.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia University, New York, N. Y.

Charles Rollin Keyes, Ph. D., 944 Fifth St., Des Moines, Iowa. Aug., 1890.

Edward M. Kindle, Ph. D., U. S. Geological Survey, Washington, D. C. December, 1905.

Frank H. Knowlton, M. S., U. S. National Museum, Washington, D. C. May, 1889.

Edward Henry Kraus, Ph. D., University of Michigan, Ann Arbor, Mich. June, 1902.

Henry B. Kümmel, Ph. D., Trenton, N. J. December, 1895.

*George F. Kunz, A. M. (Hon.), Ph. D. (Hon.), care of Tiffany & Co., Fifth Ave., at 37th St., New York, N. Y.

George Edgar Ladd, Ph. D., School of Mines, Rolla, Mo. August, 1891.

Henry Landes, A. B., A. M., University of Washington, University Station, Seattle, Wash. December, 1908.

Alfred C. Lane, Ph. D., Tufts College, Mass. December, 1889.

Andrew C. Lawson, Ph. D., University of California, Berkeley, Cal. May, 1889.

Willis Thomas Lee, M. S., U. S. Geological Survey, Washington, D. C. December, 1903.

Charles K. Leith, Ph. D., University of Wisconsin, Madison, Wis. December, 1902.

ARTHUR G. LEONARD, Ph. D., State University of North Dakota, Grand Forks, N. Dak. December, 1901.

FRANK LEVERETT, B. S., Ann Arbor, Mich. August, 1890.

JOSEPH VOLNEY LEWIS, B. E., S. B., Rutgers College, New Brunswick, N. J. December, 1906.

WILLIAM LIBBEY, Sc. D., Princeton University, Princeton, N. J. August, 1899.

WALDEMAR LINDGREN, M. E., U. S. Geological Survey, Washington, D. C. August, 1890.

FREDERICK BREWSTER LOOMIS, B. A., Ph. D., Amherst College, Amherst, Mass. December, 1909.

GEORGE DAVIS LOUDERBACK, Ph. D., University of California, Berkeley, Cal. June, 1902.

ROBERT H. LOUGHBIDGE, Ph. D., University of California, Berkeley, Cal. May, 1889.

ALBERT P. LOW, B. A. Sc., LL. D., Deputy Minister, Department of Mines, Ottawa, Canada. December, 1905.

RICHARD SWANN LULL, B. S., M. S., Ph. D., Yale University, New Haven, Conn. December, 1909.

SAMUEL WASHINGTON MCCALLIE, Ph. B., Atlanta, Ga. December, 1909.

HIRAM DEYER MCCASKEY, B. S., U. S. Geological Survey, Washington, D. C. December, 1904.

RICHARD G. MCCONNELL, A. B., Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.

JAMES RIEMAN MACFARLANE, A. B., 100 Diamond St., Pittsburgh, Pa. August, 1891.

*W J MCGEE, LL. D., Inland Waterways Commission, Washington, D. C.

WILLIAM MCINNES, A. B., Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.

PETER MCKELLAR, Fort William, Ontario, Canada. August, 1890.

GEORGE ROGERS MANSFIELD, B. S., A. M., Ph. D., Northwestern University, Evanston, Ill. December, 1909.

CURTIS F. MARBUT, A. M., State University, Columbia, Mo. August, 1897.

VERNON F. MARSTERS, A. M., Apartado 856, Lima, Peru. August, 1892.

GEORGE CURTIS MARTIN, Ph. D., U. S. Geological Survey, Washington, D. C. June, 1902.

LAWRENCE MARTIN, A. B., A. M., University of Wisconsin, Madison, Wis. December, 1909.

EDWARD B. MATHEWS, Ph. D., Johns Hopkins University, Baltimore, Md. August, 1895.

W. D. MATTHEW, Ph. D., American Museum of Natural History, New York, N. Y. December, 1903.

P. H. MELL, M. E., Ph. D., 165 East 10th St., Atlanta, Ga. December, 1888.

WALTER C. MENDENHALL, B. S., U. S. Geological Survey, Washington, D. C. June, 1902.

JOHN C. MERRIAM, Ph. D., University of California, Berkeley, Cal. Aug., 1895.

*FREDERICK J. H. MERRILL, Ph. D., Nogales, Arizona.

GEORGE P. MERRILL, Ph. D., U. S. National Museum, Washington, D. C. December, 1888.

Arthur M. Miller, A. M., State University of Kentucky, Lexington, Ky. December, 1897.

Benjamin L. Miller, Ph. D., Lehigh University, South Bethlehem, Pa. December, 1904.

Willet G. Miller, M. A., Toronto, Canada. December, 1902.

William John Miller, S. B., Ph. D., Hamilton College, Clinton, N. Y. December, 1909.

Henry Montgomery, Ph. D., University of Toronto, Toronto, Canada. December, 1904.

Malcolm John Munn, U. S. Geological Survey, Washington, D. C. Dec., 1909.

*Frank L. Nason, A. B., West Haven, Conn.

David Hale Newland, B. A., Albany, N. Y. December, 1906.

John F. Newsom, Ph. D., Leland Stanford, Jr., University, Stanford University, Cal. December, 1899.

William H. Norton, M. A., Cornell College, Mount Vernon, Iowa. Dec., 1895.

Charles J. Norwood, State University, Lexington, Ky. August, 1894.

Ida Helen Ogilvie, A. B., Ph. D., Barnard College, Columbia University, New York, N. Y. December, 1906.

Cleophas C. O'Harra, Ph. D., South Dakota School of Mines, Rapid City, S. Dak. December, 1904.

Ezequiel Ordonez, 2 a General Prine, Mexico, D. F., Mex. August, 1896.

Edward Orton, Jr., E. M., Geological Survey of Ohio, Columbus, Ohio. December, 1909.

*Amos O. Osborn,[12a] Waterville, Oneida County, N. Y.

Henry F. Osborn, Sc. D., American Museum of Natural History, New York, N. Y. August, 1894.

Charles Palache, B. S., Harvard University, Cambridge, Mass. Aug., 1897.

William A. Parks, B. A., Ph. D., University of Toronto, Toronto, Canada. December, 1906.

*Horace B. Patton, Ph. D., Colorado School of Mines, Golden, Colo.

Frederick B. Peck, Ph. D., Lafayette College, Easton, Pa. August, 1901.

Richard A. F. Penrose, Jr., Ph. D., 460 Bullitt Building, Philadelphia, Pa. May, 1889.

George H. Perkins, Ph. D., University of Vermont, Burlington, Vt.; State Geologist. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

Olaf August Peterson, Carnegie Museum, Pittsburgh, Pa. December, 1910.

Louis V. Pirsson, Ph. D., Sheffield Scientific School, Yale University, New Haven, Conn. August, 1894.

Joseph Hyde Pratt, Ph. D., North Carolina Geological Survey, Chapel Hill, N. C. December, 1898.

*Charles S. Prosser, D. Sc., Ph. D., Ohio State University, Columbus, Ohio.

*Raphael Pumpelly, Newport, R. I.

Albert Homer Purdue, B. A., University of Arkansas, Fayetteville, Ark. December, 1904.

Frederick Leslie Ransome, Ph. D., U. S. Geological Survey, Washington, D. C. August, 1895.

[12a] Deceased.

Percy Edward Raymond, B. A., Ph. D., Geological Survey, Ottawa, Canada. December, 1907.

Harry Fielding Reid, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

William North Rice, Ph. D., LL. D., Wesleyan University, Middletown, Conn. August, 1890.

Charles H. Richardson, Ph. D., Syracuse University, Syracuse, N. Y. December, 1899.

George Burr Richardson, S. B., S. M., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1908.

Heinrich Ries, Ph. D., Cornell University, Ithaca, N. Y. December, 1893.

Rudolph Ruedemann, Ph. D., Albany, N. Y. December, 1905.

Orestes H. St. John, 1141 Twelfth St., San Diego, Cal. May, 1889.

*Rollin D. Salisbury, A. M., University of Chicago, Chicago, Ill.

Frederick W. Sardeson, Ph. D., University of Minnesota, Minneapolis, Minn. December, 1892.

Thomas Edmund Savage, A. B., B. S., M. S., University of Illinois, Urbana, Ill. December, 1907.

Frank C. Schrader, M. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1901.

Charles Schuchert, Yale University, New Haven, Conn. August, 1895.

William B. Scott, Ph. D., Princeton University, Princeton, N. J. Aug., 1892.

Arthur Edmund Seaman, B. S., Michigan College of Mines, Houghton, Mich. December, 1904.

Henry M. Seely, M. D., Middlebury College, Middlebury, Vt. May, 1880.

Elias H. Sellards, Ph. D., Tallahassee, Fla. December, 1905.

Joaquim Candido da Costa Seña, State School of Mines, Ouro Preto, Brazil. December, 1908.

George Burbank Shattuck, Ph. D., Vassar College, Poughkeepsie, N. Y. August, 1899.

Solon Shedd, A. B., Washington Agricultural College, Pullman, Wash. December, 1904.

Edward M. Shepard, Sc. D., 1403 Benton Ave., Springfield, Mo. August, 1901.

Will H. Sherzer, M. S., State Normal School, Ypsilanti, Mich. Dec., 1890.

Bohumil Shimek, C. E., M. S., University of Iowa, Iowa City, Iowa. December, 1904.

Hervey Woodburn Shimer, A. B., A. M., Ph. D., Massachusetts Institute of Technology, Boston, Mass. December, 1910.

Frederick W. Simonds, Ph. D., University of Texas, Austin, Texas.

William John Sinclair, B. S., Ph. D., Princeton University, Princeton, N. J. December, 1906.

Earle Sloan, Charleston, S. C. December, 1908.

*Eugene A. Smith, Ph. D., University of Alabama, University, Ala.

Frank Clemes Smith, E. M., Richland Center, Wis. December, 1898.

George Otis Smith, Ph. D., U. S. Geological Survey, Washington, D. C. August, 1897.

Philip S. Smith, A. B., A. M., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1909.

Warren Du Pré Smith, B. S., A. M., Ph. D., Mining Bureau, Manila, Philippine Islands. December, 1909.

W. S. Tangier Smith, Ph. D., University of Nevada, Reno, Nev. June, 1902.

*John C. Smock, Ph. D., Trenton, N. J.

Charles H. Smyth, Jr., Ph. D., Princeton University, Princeton, N. J. August, 1892.

Henry L. Smyth, A. B., Harvard University, Cambridge, Mass. Aug., 1894.

Arthur Coe Spencer, B. S., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1896.

*J. W. Spencer, Ph. D., 2019 Hillyer Place, Washington, D. C.

Josiah E. Spurr, A. B., A. M., 165 Broadway, New York, N. Y. Dec., 1894.

Joseph Stanley-Brown, Cold Spring Harbor, Long Island, N. Y. Aug., 1892.

Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C. August, 1891.

*John J. Stevenson, Ph. D., LL. D., 568 West End Ave., New York, N. Y.

George Willis Stose, B. S., U. S. Geological Survey, Washington, D. C. December, 1908.

William J. Sutton, B. S., E. M., Victoria, B. C. August, 1901.

Charles Kephart Swartz, A. B., Ph. D., Johns Hopkins University, Baltimore, Md. December, 1908.

Joseph A. Taff, B. S., 1076 Flood Bldg., San Francisco, Cal. August, 1895.

James E. Talmage, Ph. D., University of Utah, Salt Lake City, Utah. December, 1897.

Ralph S. Tarr, Cornell University, Ithaca, N. Y. August, 1890.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

*James E. Todd, A. M., 1224 Rhode Island St., Lawrence, Kas.

Cyrus Fisher Tolman, Jr., B. S., University of Arizona, Tucson, Ariz. December, 1909.

*Henry W. Turner, B. S., Room 709, Mills Building, San Francisco, Cal.

Joseph B. Tyrrell, M. A., B. Sc., Room 534, Confederation Life Building, Toronto, Canada. May, 1889.

Johan A. Udden, A. M., Augustana College, Rock Island, Ill. August, 1897.

Edward O. Ulrich, D. Sc., U. S. Geological Survey, Washington, D. C. December, 1903.

*Warren Upham, A. M., Minnesota Historical Society, Saint Paul, Minn.

*Charles R. Van Hise, M. S., Ph. D., University of Wisconsin, Madison, Wis.

Frank Robertson Van Horn, Ph. D., Case School of Applied Science, Cleveland, Ohio. December, 1898.

Gilbert van Ingen, Princeton University, Princeton, N. J. December, 1904.

Thomas Wayland Vaughan, B. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1896.

Arthur Clifford Veach, U. S. Geological Survey, Washington, D. C. December, 1906.

*Anthony W. Vogdes, 2425 First St., San Diego, Cal.

*M. Edward Wadsworth, Ph. D., School of Mines, University of Pittsburgh, Pittsburgh, Pa.

*Charles D. Walcott, LL. D., Smithsonian Institution, Washington, D. C.

Thomas L. Walker, Ph. D., University of Toronto, Toronto, Canada. December, 1903.

Charles H. Warren, Ph. D., Massachusetts Institute of Technology, Boston, Mass. December, 1901.

Henry Stephens Washington, Ph. D., Locust, Monmouth Co., N. J. August, 1896.

Thomas L. Watson, Ph. D., University of Virginia, Charlottesville, Va. June, 1900.

Walter H. Weed, E. M., Norwalk, Conn. May, 1889.

Fred. Boughton Weeks, U. S. Geological Survey, Washington, D. C. December, 1903.

Samuel Weidman, Ph. D., Wisconsin Geological and Natural History Survey, Madison, Wis. December, 1903.

Stuart Weller, B. S., University of Chicago, Chicago, Ill. June, 1900.

Lewis G. Westgate, Ph. D., Ohio Wesleyan University, Delaware, Ohio.

David White, B. S., U. S. National Museum, Washington, D. C. May, 1889.

*Israel C. White, Ph. D., Morgantown, W. Va.

George Reber Wieland, B. S., Ph. D., Yale University, New Haven, Conn. December, 1910.

Frank A. Wilder, Ph. D., North Holston, Smyth Co., Va. December, 1905.

*Edward H. Williams, Jr., A. C., E. M., Woodstock, Vt.

*Henry S. Williams, Ph. D., Cornell University, Ithaca, N. Y.

Ira A. Williams, M. Sc., Iowa State College, Ames, Iowa. December, 1905.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

Samuel W. Williston, Ph. D., M. D., University of Chicago, Chicago, Ill. December, 1889.

Arthur B. Willmott, M. A., 24 Adelaide St., W., Toronto, Canada. December, 1899.

Alfred W. G. Wilson, Ph. D., Mines Branch, Department of Mines, Ottawa, Canada. June, 1902.

Alexander N. Winchell, Doct. U. Paris, University of Wisconsin, Madison, Wis. August, 1901.

*Horace Vaughn Winchell, 505 Palace Building, Minneapolis, Minn.

*Newton H. Winchell, A. M., 501 East River Road, Minneapolis, Minn.

*Arthur Winslow, B. S., 131 State St., Boston, Mass.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass. Dec., 1889.

Joseph E. Woodman, S. D., New York University, New York, N. Y. Dec., 1905.

Robert S. Woodward, C. E., Carnegie Institution of Washington, Washington, D. C. May, 1889.

Jay B. Woodworth, B. S., Harvard University, Cambridge, Mass. Dec., 1895.

Charles Will Wright, B. S., M. E., U. S. Geological Survey, Washington, D. C. December, 1909.

Frederic E. Wright, Ph. D., Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1903.

*G. Frederick Wright, D. D., Oberlin Theological Seminary, Oberlin, Ohio.

George A. Young, Ph. D., Geological Survey of Canada, Ottawa, Canada. December, 1905.

FELLOWS DECEASED

***Indicates Original Fellow (see article III of Constitution)**

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.

Charles E. Beecher, Ph. D. Died February 14, 1904.

William Phipps Blake. Died May 21, 1910.

Amos Bowman. Died June 18, 1894.
Franklin R. Carpenter. Died April 1, 1910.
*J. H. Chapin, Ph. D. Died March 14, 1892.
*Edward W. Claypole, D. Sc. Died August 17, 1901.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
*Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio Del Castillo. Died October 28, 1895.
*James D. Dana, LL. D. Died April 14, 1895.
George M. Dawson, D. Sc. Died March 2, 1901.
Sir J. William Dawson, LL. D. Died November 19, 1899.
*William B. Dwight, Ph. B. Died August 29, 1906.
*George H. Eldridge, A. B. Died June 29, 1905.
*Albert E. Foote. Died October 10, 1895.
*Persifor Frazer. Died April 7, 1909.
*Homer T. Fuller. Died August 14, 1908.
N. J. Giroux, C. E. Died November 30, 1890.
*James Hall, LL. D. Died August 7, 1898.
John B. Hatcher, Ph. B. Died July 3, 1904.
*Robert Hay. Died December 14, 1895.
*Angelo Heilprin. Died July 17, 1907.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Alpheus Hyatt, B. S. Died January 15, 1902.
*Joseph F. James, M. S. Died March 29, 1897.
Wilbur C. Knight, B. S., A. M. Died July 28, 1903.
Ralph D. Lacoe. Died February 5, 1901.
J. C. K. Laflamme. Died July 6, 1910.
Daniel W. Langton. Died June 21, 1909.
*Joseph Le Conte, M. D., LL. D. Died July 6, 1901.
*J. Peter Lesley, LL. D. Died June 2, 1903.
Henry McCalley, A. M., C. E. Died November 20, 1904.
Oliver Marcy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
James E. Mills, B. S. Died July 25, 1901.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*Peter Neff, M. A. Died May 11, 1903.
*John S. Newberry, M. D., LL. D. Died December 7, 1892.
William H. Niles. Died September 12, 1910.
*Edward Orton, Ph. D., LL. D. Died October 16, 1899.
*Richard Owen, LL. D. Died March 24, 1890.
Samuel L. Penfield. Died August 14, 1906.
David Pearce Penhallow. Died October 20, 1910.
*Franklin Platt. Died July 24, 1900.
William H. Pettee, A. M. Died May 26, 1904.
*John Wesley Powell, LL. D. Died September 23, 1902.
*Israel C. Russell, LL. D. Died May 1, 1906.
*James M. Safford, M. D., LL. D. Died July 3, 1907.
*Charles Schaeffer, M. D. Died November 23, 1903.
*Nathaniel S. Shaler, LL. D. Died April 10, 1906.

William G. Tight, A. M., Ph. D. Died January 15, 1910.
Charles Wachsmuth. Died February 7, 1896.
Thomas C. Weston. Died July 20, 1910.
Theodore G. White, Ph. D. Died July 7, 1901.
*George H. Williams, Ph. D. Died July 12, 1894.
*Robert P. Whitfield, A. M. Died April 6, 1910.
*J. Francis Williams, Ph. D. Died September 9, 1891.
*Alexander Winchell, LL. D. Died February 19, 1891.
Albert A. Wright, Ph. D. Died April 2, 1905.
William S. Yeates. Died February 19, 1908.

Summary

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 22, PP. 85-102 MARCH 31, 1911

PROCEEDINGS OF THE SECOND ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT PITTSBURGH, PENNSYLVANIA, DECEMBER 28-29, 1910

R. S. BASSLER, *Secretary*

CONTENTS

SESSION OF WEDNESDAY, DECEMBER 28, 1910

The first session of the Society was called to order by President Charles Schuchert at 10 o'clock a. m., Wednesday, December 28, 1910, in the Carnegie Museum. Dr. W. J. Holland cordially welcomed the Society to Pittsburgh, and President Schuchert made an appropriate response on behalf of the members.

The report of the Council, consisting of the separate reports of the officers, was next in order and was read by the Secretary.

REPORT OF THE SECRETARY

To the members of the Paleontological Society:

At a meeting of the Council, held at the close of the Boston meeting, the resignation of Prof. H. F. Cleland as Secretary to the Society was

announced by the President, who appointed R. S. Bassler, of Washington, D. C., as Secretary, to act until elected in regular order. This action was confirmed by the members of the Council present, and later by the remaining members. At the same meeting and by further correspondence the list of officers for 1911 was arranged, and, in accordance with the By-Laws of the Society, this was forwarded to the members on March 19, 1910. At the same time it was announced that the Society would hold its second annual meeting at Pittsburgh, Pennsylvania, beginning December 28, 1910, at the invitation of the Carnegie Museum, extended through the Director, Dr. W. J. Holland.

The question regarding the publication of papers read at the first annual meeting of the Society then came before the Council, and it was voted that the conference papers on the Aspects of Paleontology should not be printed by the Society in the Bulletin of the Geological Society of America, and that the question regarding the remaining papers should be referred for further discussion and report to a committee, consisting of Dr. E. O. Hovey, representing the Geological Society of America, and Prof. Charles Schuchert, President of the Paleontological Society. This committee agreed to report to their respective councils the following plan, which was adopted in due order by each Council:

All strictly paleontological papers are to appear in the Bulletin of the Geological Society of America in the order of their approval for printing. Above each title will appear:

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 00, PP. 000-000, PLS. 00-00 (DATE)

(Proceedings of the Paleontological Society)

[TITLE OF THE PAPER AND AUTHOR]

(Read before the Paleontological Society, [Date])

Of all of these papers the Paleontological Society can purchase at about cost and without covers as many extras as wanted. These can then be covered and distributed as the Society sees fit to the members (the Fellows, of course, are supplied through the Geological Society of America). The covers are to be printed at the expense of the Paleontological Society and will have upon them:

Proceedings of the Paleontological Society

[Reprinted from the BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA, Vol. 00, pp. 000-000, pls. 00-00. (*Date*)]

[TITLE OF PAPER AND AUTHOR]

Under this arrangement the Editor of the Geological Society of America will attend to the printing of such papers. The Council also voted to accept not more than $400 from the Geological Society of America to be used in publishing strictly paleontologic papers in the Bulletin of that Society. This sum of money will not print all of the papers offered for publication during 1910, and in the future will probably be less adequate, but many of the members of the Paleontological Society have other outlets for publication.

The Council further agreed to publish a list of its entire membership as *members,* making no distinction between Fellows and members.

By a later arrangement Prof. J. McKeen Cattell kindly consented to publish the conference papers of the first annual meeting in the Popular Science Monthly. These papers appeared from time to time throughout the year in the order of their presentation at Boston, and at the close of the year were bound together in a single volume and copies sent to the members.

In April the Council voted an allowance of $50 annually to the Secretary of the Paleontological Society to help pay the expenses connected with his office, this allowance to be paid by the Treasurer at or toward the close of each year on presentation of the bill for services.

Early in the same month the President announced to the Council that the American Society of Vertebrate Paleontologists would vote to amalgamate with the Paleontological Society. In July official notice was received from President Merriam of the former Society that in their second and final vote their members had agreed "for union and to give up their constitution and identify themselves with the Paleontological Society." Later in the year (November 1, 1910) notice was received that the above vote had been acted upon, dues returned to the members, and the remaining money turned over to the Treasurer of the Paleontological Society. Of the 45 members of the American Society of Vertebrate Paleontologists, 21 were already members of the Paleontological Society, so it only remained for the other 24 to signify their willingness to join our Society. Most of these have accepted, and the rolls at present contain 126 names.

In October the Council voted that Prof. J. C. Merriam be authorized to organize a Pacific Coast section of the Paleontological Society, in harmony with the constitution of that Society, and that it be known as the Cordilleran Section of the Paleontological Society.

During the year we have lost by death three members—Prof. R. P. Whitfield, Prof. D. P. Penhallow, and Mr. Robert H. Gordon.

All of the nominations for members were approved by the Council and offered for election prior to the annual meeting, December 28, 1910. The list is given on another page.

The Council nominated for election as correspondents the following: Prof. Dr. A. G. Nathorst, Royal Natural History Museum, Stockholm, Sweden; Prof. Dr. E. Koken, Tübingen, Germany; Mr. S. S. Buckman, Westfield, Thame, England, and Prof. Charles Déperet, Lyon (Rhone), France.

Five members of the Society—Prof. Bashford Dean, Dr. W. J. Holland, Mr. Louis Hussakof, Mr. O. A. Peterson, and Mr. G. R. Wieland—were proposed by the Council of the Paleontological Society as candidates for election to Fellowship in the Geological Society of America. Two other members—Mr. Barnum Brown and Prof. H. W. Shimer—would have been nominated in the same way had their names not been offered by individual Fellows of the two societies.

Acting upon the suggestion that it would be well if each annual meeting had the impress of that branch of paleontologic study pursued by the President, Professor Schuchert proposed a conference on the Criteria in Paleozoic Paleogeography for the Pittsburgh meeting, to occupy one-half day. The Council agreed to this plan, and the program printed on a following page was arranged.

At the regular annual meeting of the Council held in the Schenley Hotel, December 27, 1910, the following matters of business were considered:

It was voted that hereafter the Secretary of the Society shall attend to and be responsible for all the printing save the papers published for the Society by the Geological Society of America. It was also voted that all of the papers hereafter published by the Paleontological Society be sent to all of its members. It was the sense of the Council that the dues of the members received into the Society through amalgamation with the Society of American Vertebrate Paleontologists should begin with the coming year.

Respectfully submitted, R. S. Bassler, *Secretary.*

December 20, 1910.

Report of the Treasurer

To the Council of the Paleontological Society:

The funds in the Treasurer's hands are the dues of members for the years 1909 and 1910. Of these, twenty-one have paid and two are delinquent for 1909, and twenty-seven have paid the dues for 1910, and thirteen are delinquent. The Treasurer has also received from the American Society of Vertebrate Paleontologists the balance in the treasury of that Society at its dissolution. No bills have thus far been presented for payment by the present or former Secretary of the Paleontological Society.

The funds at present standing in the treasury are as follows:

	Dr.	Cr.
Dues of members for 1909	$63.00	
Dues of members for 1910	81.00	
Balance of funds of the American Society of Vertebrate Paleontologists	1.87	
Exchange on out-of-town checks	......	$1.60
Postage (Treasurer, 1909, 1910)	......	2.36
Balance on hand	......	141.91
	$145.87	$145.87

Respectfully submitted,

W. D. Matthew, *Treasurer.*

American Museum of Natural History, New York, December 23, 1910.

Following the reading of the Treasurer's report, the Chair appointed Stuart Weller and T. W. Stanton as a committee to audit the report.

ELECTION OF OFFICERS, CORRESPONDENTS, AND MEMBERS

The declaration of the votes for officers for 1911, for correspondents, and for members was next in order, and was announced by the Secretary as follows:

OFFICERS FOR 1911

President:

William B. Scott, Princeton, N. J.

First Vice-President:

Arthur Hollick, New York City

Second Vice-President:

W. D. Matthew, New York City

Third Vice-President:

Stuart Weller, Chicago, Ill.

Secretary:

R. S. Bassler, Washington, D. C.

Treasurer:

Richard S. Lull, New Haven, Conn.

Editor:

Charles R. Eastman, Cambridge, Mass.

CORRESPONDENTS

Prof. Dr. A. G. Nathorst, Royal Natural History Museum, Stockholm, Sweden.
Prof. Dr. E. Koken, University of Tübingen, Tübingen, Germany.
S. S. Buckman, Esq., Westfield, Thame, England.
Prof. Charles Déperet, University of Lyon, Lyon (Rhone), France.

MEMBERS

Walter R. Billings, 1250 Bank Street, Ottawa, Canada.
Lancaster D. Burling, U. S. National Museum, Washington, D. C.
John Merle Coulter, University of Chicago, Chicago, Ill.
George W. Harper, 2139 Gilbert Avenue, Cincinnati, Ohio.
John M. Jessup, Smithsonian Institution, Washington, D. C.
Victor W. Lyon, Jeffersonville, Indiana.
Wendell C. Mansfield, U. S. Geological Survey, Washington, D. C.
Thomas Poole Maynard, Assistant State Geologist, Atlanta, Ga.
Paul V. Roundy, U. S. Geological Survey, Washington, D. C.
Chester Albert Reeds, Yarrow West, Bryn Mawr, Pa.
William Henry Twenhofel, 1515 Vermont St., Lawrence, Kansas.

RESOLUTION CONCERNING ZOOLOGICAL NOMENCLATURE

The President then announced that the Council had been considering the advisability of having the Society represented in the discussions on zoological nomenclature, and he instructed the Secretary to read the following resolution toward this end, drawn up by the Council:

Resolved, That a committee of three (3), representing the three branches of the Paleontological Society, be appointed by the President, with the advice and consent of the Council, to act in cooperation with the International Commission on Zoological Nomenclature and any other similar bodies. Further, that the findings of this committee in the shape of recommendations be submitted to the Council, which in turn will transmit them to the Society for final action and approval.

This resolution was accepted as a motion, which was seconded, and, after discussion by W. J. Holland, John M. Clarke, S. W. Williston, and Charles Schuchert, was adopted. The chair then appointed S. W. Williston as chairman, W. H. Dall, and F. H. Knowlton as a committee to represent the Society in this matter.

RESOLUTION CONCERNING FREIGHT CLASSIFICATION

The unjust classification of unworked rock masses containing fossils as first-class freight was brought to the attention of the Society by W. J. Holland, and, after discussion, a resolution was passed identical with that passed December 27, 1910, and given on page 53 of this volume.

Gilbert van Ingen called the attention of the Society to the action of the Pennsylvania Railroad in excluding persons from its tracks and to the necessity of obtaining written permission for geologic work along the line of this railway.

MEMORIAL ADDRESSES

President Schuchert then spoke of the Society's loss by death during the year of Prof. R. P. Whitfield, Prof. D. P. Penhallow, and Mr. Robert H. Gordon. John M. Clarke addressed the Society on the life and work of Professor Whitfield, F. H. Knowlton read a memorial on Professor Penhallow's influence in paleobotany, and President Schuchert told of the work of Mr. Gordon on Maryland geology and paleontology.

TITLES OF PAPERS ON PALEOBOTANY AND NAMES OF DISPUTANTS

After announcement by the President of arrangements for the various meetings of the Society, the reading of the scientific papers, beginning with paleobotany, was taken up.

RESULTS OF A PRELIMINARY INVESTIGATION OF THE KENAI FLORA OF ALASKA

BY ARTHUR HOLLICK

Read in the absence of the author by F. H. Knowlton, illustrated by specimens; 10 minutes. Discussed by G. R. Wieland and David White.

A NEW GENERIC TYPE OF FOSSIL FERN FROM THE AMERICAN TERTIARY

BY F. H. KNOWLTON

Read from manuscript, illustrated with drawings; 10 minutes. Discussed by C. Schuchert.

THE COTYLEDONARY NODE OF CYCADEOIDEA

BY G. R. WIELAND

Presented without manuscript; 15 minutes. Discussed by David White and the author.

GIGANTOPTERIS SCHENK, ITS CHARACTER AND OCCURRENCE IN AMERICA

BY DAVID WHITE

Read from manuscript by the author and illustrated with photographs; 20 minutes. Discussed by Gilbert van Ingen, C. Schuchert, John M. Clarke, G. R. Wieland, and the author.

At 12.30 p. m. the Society adjourned for luncheon at the Schenley Hotel, convening again at 2 p. m., in conjunction with the Geological Society of America, to hear the address of the retiring President of the Paleontological Society, Dr. J. M. Clarke. Doctor Clarke spoke upon:

1. The paleontologist and the public.
2. The paleontology of right living.

TITLES OF PAPERS ON INVERTEBRATE PALEONTOLOGY AND NAMES OF DISPUTANTS

After the presidential address the Society retired to its own lecture hall for the reading of papers dealing with invertebrate paleontology.

THE NEW STRATIGRAPHIC UNITS OF THE HUNTON FORMATION, OKLAHOMA

BY CHESTER A. REEDS

Presented without manuscript; illustrated with lantern slides; 20 minutes. Discussed by C. Schuchert and David White.

GENERA OF MISSISSIPPIAN LOOP-BEARING BRACHIOPODA

BY STUART WELLER

Read from manuscript; illustrated with lantern slides; 15 minutes. Discussed by C. Schuchert and J. M. Clarke.

ORDOVICIAN AND SILURIAN POLAR FAUNAS

BY R. S. BASSLER

Presented without manuscript; illustrated with lantern slides; 20 minutes. Discussed by Stuart Weller, W. J. Holland, G. R. Wieland, Charles Schuchert, and J. M. Clarke.

At 5.30 the Society adjourned for the day.

Wednesday evening the members of the Society took part in the customary annual dinner with the Fellows of the Geological Society of America.

Session of Thursday, December 29, 1910

Thursday morning the Society was called to order at 10 o'clock by President Schuchert, who announced that the morning would be devoted to the conference on the Criteria in Paleozoic Paleogeography. The

Auditing Committee reported that the Treasurer's accounts were correct, and their report was accepted.

TITLES OF CONFERENCE PAPERS AND NAMES OF DISPUTANTS

The program of the morning session was as follows:

THE NATURE OF TERTIARY AND MODERN MARINE FAUNAL BARRIERS AND CURRENTS

BY W. H. DALL

Read in the absence of the author by the Secretary. Discussed by C. Schuchert, E. O. Ulrich, David White, and C. D. Walcott.

THE VALUE OF FLORAL EVIDENCE IN MARINE STRATA AS INDICATIVE OF NEARNESS OF SHORES

BY DAVID WHITE

Discussed by C. Schuchert.

ARE THE FOSSILS OF DOLOMITES INDICATIVE OF SHALLOW, HIGHLY SALINE, AND WARM SEAS?

BY STUART WELLER

Discussed by E. O. Ulrich, J. M. Clarke, Gilbert van Ingen, R. S. Bassler, C. Schuchert, H. P. Cushing, C. D. Walcott, and W. A. Parks.

THE PHYSICAL CONDITIONS UNDER WHICH PALEOZOIC CORAL REEFS WERE FORMED

BY T. WAYLAND VAUGHAN

Read in the absence of the author by the Secretary. Discussed by C. Schuchert and Gilbert van Ingen.

THE STRATIGRAPHIC SIGNIFICANCE OF GRAPTOLITES

BY R. RUEDEMANN

Discussed by Gilbert van Ingen and C. Schuchert.

THE RELATIONS OF PALEOZOIC BRYOZOA TO PALEOGEOGRAPHY

BY E. O. ULRICH

THE STRATIGRAPHIC SIGNIFICANCE OF BRACHIOPODA

BY CHARLES SCHUCHERT

Discussed by J. M. Clarke.

THE STRATIGRAPHIC SIGNIFICANCE OF OSTRACODA

BY R. S. BASSLER

Discussed by J. M. Clarke and W. J. Holland.

THE RELATION OF THE PALEOZOIC ARTHROPODS TO THE STRAND LINE

BY JOHN M. CLARKE

Discussed by C. Schuchert.

The final paper of the series, entitled

THE PALEOGEOGRAPHIC SIGNIFICANCE OF LAND VERTEBRATES IN PALEOZOIC STRATA

BY S. W. WILLISTON

was omitted at this point, but was presented by the author during the afternoon session, in connection with his other papers on vertebrate paleontology.

At 12.30 the Society adjourned to meet at 2 p. m. for the reading of papers on vertebrate paleontology. Vice-President Williston presided at this session.

TITLES OF PAPERS ON VERTEBRATE PALEONTOLOGY AND NAMES OF DISPUTANTS

The program of the afternoon session, in so far as it related to vertebrate paleontology, was as follows:

A NEW DINOSAUR FROM THE TRIASSIC OF THE CONNECTICUT VALLEY

BY MIGNON TALBOT

Presented without manuscript and illustrated with lantern slides; 10 minutes. Discussed by S. W. Williston.

THE SKULL OF MOROPUS ELATUS MARSH

BY W. J. HOLLAND

Presented without manuscript and illustrated with specimens and lantern slides; 20 minutes. Discussed by S. W. Williston.

THE CARNEGIE DINOSAUR QUARRY IN UINTAH COUNTY, UTAH

BY W. J. HOLLAND

Given without manuscript and illustrated with a model and with lantern slides; 20 minutes.

A MOUNTED SKELETON OF DICERATHERIUM COOKI PETERSON IN THE CARNEGIE MUSEUM

BY O. A. PETERSON

Presented without manuscript and illustrated with specimens and lantern slides; 10 minutes. Discussed by S. W. Williston.

A NEW CAMEL FROM THE MIOCENE OF NEBRASKA

BY O. A. PETERSON

Presented without manuscript and illustrated with lantern slides and specimens; 5 minutes. Discussed by W. J. Holland.

REMARKS ON THE FOSSIL TURTLES ACCREDITED TO THE JUDITH RIVER FORMATION

BY F. H. KNOWLTON

Read from manuscript; 10 minutes. Discussed by G. R. Wieland.

THE LAMBDOTHERIUM ZONE IN THE BIGHORN BASIN, WYOMING

BY WM. J. SINCLAIR AND WALTER GRANGER

Presented by Wm. J. Sinclair and illustrated with lantern slides; 15 minutes.

A MOUNTED SKELETON OF VARANOSAURUS FROM THE PERMIAN OF TEXAS

BY S. W. WILLISTON

Presented without manuscript and illustrated with photographs; 10 minutes.

A COMPLETE SKELETON OF A NEW GROUP OF LARGE REPTILES FROM THE PERMIAN OF NEW MEXICO

BY S. W. WILLISTON

Presented without manuscript and illustrated with lantern slides; 10 minutes.

TITLES OF PAPERS ON INVERTEBRATE AND GENERAL PALEONTOLOGY AND NAMES OF DISPUTANTS

The papers on vertebrate paleontology having been completed, President Schuchert resumed the chair, and the remaining papers on invertebrate and general paleontology were presented.

FOSSIL MEDUSAE FROM CAMBRIAN ROCKS OF BRITISH COLUMBIA

BY CHARLES D. WALCOTT

Presented without manuscript and illustrated with lantern slides; 15 minutes. Discussed by John M. Clarke.

DISCOVERY OF ANTENNAE AND OTHER APPENDAGES OF MIDDLE CAMBRIAN TRILOBITES

BY CHARLES D. WALCOTT

Given without manuscript and illustrated with lantern slides and specimens; 10 minutes. Discussed by J. M. Clarke and C. Schuchert.

In the absence of the author, the following paper was read by title:

"MUTATIONS" OF WAAGEN AND "MUTATIONS" OF DE VRIES, OR RECTIGRADATIONS OF OSBORN COMPARED

BY H. F. OSBORN

At the request of their respective authors, the time for adjournment having arrived, the two following papers were read by title:

ON THE DERIVATION OF PALEOZOIC FAUNAS

BY E. O. ULRICH

THE LABRADOR-NEWFOUNDLAND PALEOZOIC SECTION

BY CHARLES SCHUCHERT

President Schuchert then expressed the thanks of the Society to the Carnegie Museum, through Director W. J. Holland, for the many courtesies and the completeness of the arrangements made for the meeting. Upon motion, the Society then adjourned.

Register of the Pittsburgh Meeting, 1910

R. S. Bassler
Samuel Calvin
William Bullock Clark
John M. Clarke
C. R. Eastman
August F. Foerste
C. N. Gould
C. A. Hartnagel
W. J. Holland
F. H. Knowlton
W. A. Parks
O. A. Peterson
Charles S. Prosser
Percy E. Raymond
Rudolph Ruedemann
Charles Schuchert
W. J. Sinclair
T. W. Stanton
C. R. Stauffer
Mignon Talbot
E. O. Ulrich
Gilbert van Ingen
Charles D. Walcott
Stuart Weller
David White
G. R. Wieland
S. W. Williston

MEMBER-ELECT

Chester A. Reeds

OFFICERS AND MEMBERS OF THE PALEONTOLOGICAL SOCIETY

OFFICERS FOR 1911

President:

William B. Scott, Princeton, N. J.

First Vice-President:

Arthur Hollick, New York City

Second Vice-President:

W. D. Matthew, New York City

Third Vice-President:

Stuart Weller, Chicago, Ill.

Secretary:

R. S. Bassler, Washington, D. C.

Treasurer:

Richard S. Lull, New Haven, Conn.

Editor:

Charles R. Eastman, Cambridge, Mass.

CORRESPONDENTS

Prof. Dr. A. C. Nathorst, Royal Natural History Museum, Stockholm, Sweden.
Prof. Dr. E. Koken, University of Tübingen, Tübingen, Germany.
S. S. Buckman, Esq., Westfield, Thame, England.
Prof. Charles Déperet, University of Lyon, Lyon (Rhone), France.

MEMBERS, DECEMBER 31, 1910

José Guadalupe Aguilera, Ph. D., City of Mexico, Mexico; Director del Instituto Geologico de Mexico.
Truman H. Aldrich, M. E., 1739 P St. N. W., Washington, D. C.
Henry M. Ami, A. M., Ottawa, Canada; Assistant Paleontologist, Geological and Natural History Survey of Canada.
Robert Anderson, U. S. Geological Survey, Washington, D. C.
Ralph Arnold, Ph. D., 726 H. W. Hellman Bldg., Los Angeles, Cal.
Rufus Mather Bagg, Jr., Ph. D., 603 W. Green St., Urbana, Ill.; Instructor in Geology, University of Illinois.

Edwin Hinckley Barbour, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist.

Ray Smith Bassler, Ph. D., Washington, D. C.; Curator U. S. National Museum.

Joshua W. Beede, Ph. D., Bloomington, Ind.; Associate Professor of Geology, Indiana University.

B. A. Bensley, Ph. D., Toronto, Canada; Associate Professor of Zoology, University of Toronto.

Edward Wilber Berry, Baltimore, Md.; Associate in Paleontology, Johns Hopkins University.

Arthur B. Bibbins, Ph. B., Baltimore, Md.; Instructor in Woman's College.

Emil Böse, Ph. D., City of Mexico, Mexico; Instituto Geologico de Mexico.

E. B. Branson, Ph. D., Columbia, Mo.; Professor of Geology, University of Missouri.

Barnum Brown, A. B., New York, N. Y.; Assistant Curator of Fossil Reptiles, American Museum of Natural History.

Carl Burckhardt, Ph. D., City of Mexico, Mexico; Instituto Geologico de Mexico.

Samuel Calvin, Ph. D., LL. D., Iowa City, Iowa; State Geologist; Professor of Geology, State University of Iowa.

Ermine C. Case, Ph. D., Ann Arbor, Mich.; Department of Geology, University of Michigan.

F. C. Clark, Los Angeles, California.

William Bullock Clark, Ph. D., Baltimore, Md.; Professor of Geology, Johns Hopkins University; State Geologist.

John Mason Clarke, A. M., Albany, N. Y.; State Geologist and Paleontologist.

Herdman F. Cleland, Ph. D., Williamstown, Mass.; Professor of Geology, Williams College.

Harold J. Cook, Agate, Neb.

Edgar R. Cumings, Ph. D., Bloomington, Ind.; Professor of Geology, Indiana University.

W. H. Dall, A. M., Sc. D., Smithsonian Institution, Washington, D. C.; Paleontologist, U. S. Geological Survey.

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ORIGIN OF THE THERMAL WATERS IN THE YELLOWSTONE NATIONAL PARK [1]

ANNUAL ADDRESS OF THE PRESIDENT, ARNOLD HAGUE

(*Read before the Society December 27, 1910*)

CONTENTS

INTRODUCTION

From the earliest days of systematic geological research thermal springs have been a frequent subject of investigations by students of natural phenomena. From time to time numerous contributions to scientific literature bearing on the nature of hot springs, partly descriptive and in part theoretical, have been presented to learned societies. Nearly all regions where such waters issue from the ground on an imposing scale appear to have been at one time or another scenes of eruptive energy. In so many instances has this been shown to be the case that thermal activity and volcanic manifestations have come to be regarded as associated phenomena. It by no means follows, however, that the original source of all these waters was, geologically speaking, deep-seated, and by a large school of geologists it has never been so regarded. In recent years the results of several suggestive researches have been published, in which the position

[1] Manuscript received by the Secretary of the Society January 17, 1911.

is taken that superheated waters issuing from igneous rocks are primitive in their origin—that is to say, they are derived from great depths in the earth's crust and are brought to the surface for the first time by volcanic forces.

The Yellowstone National Park affords one of the most remarkable, and probably one of the most instructive, areas of thermal springs and geysers to be found in the world. The varied phenomena of boiling springs and aqueous vapors there stand unsurpassed. Several years ago, after a study of the region under the auspices of the United States Geological Survey, I published in official documents, and later in Johnson's Universal Cyclopædia, an article entitled "Thermal Springs," in which I stated the conclusion that the waters of these hot springs and geysers were essentially meteoric waters that had penetrated downwards a sufficient distance to attain an increased temperature, only to be forced again to the surface by ascending currents.

I propose on this occasion to present briefly some of the geological evidence on which these conclusions are founded. They are based on the nature and structure of the rocks through which the heated waters reach the surface, the mineral constituents contained in the waters, the composition of the associated gases, and the characters of the varied sediments and incrustations deposited around the springs and pools.

Eocene Igneous Rocks

To understand correctly the relations of the thermal waters found in the park to existing geological conditions, a brief history of the salient features of its igneous rocks and their sequence seems necessary. The country included within the Yellowstone Park, the Absaroka Range, and the Wind River Plateau consists essentially of masses of igneous rocks covering an area of over 5,000 square miles in the center of a continent whose three great rivers, the Mississippi, the Colorado, and the Columbia, here find their source. Within this region, through that vast period of time from the close of the Archean to the dawn of the Tertiary, all evidences of eruptive energy are wanting. Coincident with the earliest indications of the post-Laramie orogenic movement came a period of intrusion which began in late Cretaceous time and continued with only slight periods of rest till near the end of the Pliocene. Whatever the primary causes were that produced this orogenic movement, the enlargement of the continental area, and the final withdrawal of the sea, they brought about mountain uplifts, crustal displacements, and volcanic activities of the first magnitude. The close of the Cretaceous in this part of the northern Cordillera was marked by the most profound strati-

graphic break since Algonkian time. The oldest intrusives, recognized as such, are found in the northwestern corner of the Yellowstone Park in what is now the Gallatin Range, and inaugurated a physical revolution. These rocks were forced in as sills between Upper Mesozoic sandstones before the latter were much disturbed, as they lie unconformably interbedded between sediments which later were affected by the dynamic processes of mountain elevation. In this sense these earliest intrusions must be considered, structurally at least, as of Cretaceous age. They were succeeded by more powerful injections, accompanied by slow and protracted elevation of the Gallatin Range. With the emergence of land surfaces erosion followed and sediments were deposited unconformably. Elevation of mountain masses produced new physiographic features, and as a consequence changes in climatic conditions and modifications of living species, both animal and vegetable. The Tertiary period was ushered in. With the progressive building up of the range and the associated folding and compression of strata, viscous magmas were injected from unknown depths. Massive bodies were forced upward to definite levels, when, being unable to rise higher, they spread out laterally between strata of all ages, from the Cambrian to the Laramie. Centers of powerful intrusion shifted from one locality to another, and within the confined limits of the range batholiths of no mean proportions were forced upward. Evidence is wanting to show that any of these magmas in their upward movement ever penetrated to the surface; apparently they came to a standstill far below a covering of overlying sediments, whose thickness must, for the present at least, remain a matter of conjecture. Excessive erosion since early Eocene time has laid bare these massive batholithic forms, which now stand out as dominant features in the landscape.

There is no evidence to warrant the opinion that these porphyries and crystalline rocks were ever connected with vents discharging lavas, though there is, beyond the boundaries of the Gallatin Range, extravasated material of Eocene age covering large tracts of country. In the northeast corner of the park such surface flows are well developed in the accumulation of silts and ashes. Much of this material was laid down under relatively quiet conditions. Apparently they are much later than the crystalline rocks already referred to, but their age is determined by a characteristic flora corresponding with the well known Fort Union beds of Montana of Eocene age.

In these extravasated lavas the influence of volcanic waters may be recognized in many ways, but degradation of the mass has been so great that evidence of individual extinct hot springs is no longer traceable; moreover, it would seem impossible to distinguish them from those belonging to Miocene eruptions.

Miocene Igneous Rocks and thermal Waters

The Absaroka Range shuts in the Park Plateau along its eastern border. Strictly speaking, it is not a mountain range, but rather a rugged, deeply dissected tableland, rising from 3,000 to 4,000 feet above the general level of the park. It stretches for 80 miles in a north and south direction and measures nearly 50 miles in width. In strong contrast to the Eocene igneous rocks, this elevated tableland was steadily built up by tumultuous accumulations of breccias, agglomerates, silts, and muds, the products of violent explosive action through numerous conduits from sources now concealed beneath the overlying load. Nearly all phenomena of ejected lavas seen in extinct volcanic areas elsewhere may be observed here. Finally the mass was penetrated by batholithic intrusions, accompanied by innumerable dikes and sills, offshoots from the parent stock. All this was the result of long-continued, protracted energy, as clearly shown both by geological processes and the many successive fossil forests. These flourished through thousands of feet of eruptive material, and were alternately killed by hot fragmentary lavas and preserved by renewed streams of muds and ashes.[2] The luxuriant vegetation which developed throughout this period is regarded by all paleobotanists as of Miocene age. All volcanic activity long since ceased.

What concerns us most at the present time is the influence of thermal waters, derived from deep-seated subcrustal sources on both the volcanic ejectamenta and crystalline intrusives. The action of these heated waters may be observed equally well on what were surface flows and on the deeply buried intrusive masses. Such surface action may be detected at a number of localities by the presence of alteration products and traces of sediments, although in most cases the latter have been removed by running water. Underground action of subcrustal waters is shown in many places from one end of the range to the other by deposits laid down from ascending igneous emanations in the form of aqueous and gaseous vapors charged with mineral matter. Such deposits consist essentially of quartz, galena, and copper minerals carrying both gold and silver. They lie as contact products along the apophyses of the massive intrusions and never occur far away from them. They were deposited after the crystalline intrusives came to a state of rest, but probably long before they were chilled. It may not be necessary to add, but it should be borne in mind, that at the time of deposition they were much farther below the surface than they are found today. Mining companies have exploited the ores by shifts and tunnels, but so far as I know such

[2] Arnold Hague: Early Tertiary volcanoes of the Absaroka Range. Presidential address, Geological Society of Washington, 1899. Science, ——.

ore bodies have never proved lucrative, owing to their uncertainty and lack of continuity. Similar ore bodies in the mining regions of Montana and Colorado have been described by Emmons, Lindgren, Weed, Kemp, and others.

Another feature of these intrusive rocks of the Absarokas is seen in the narrow rifts and shrinkage cracks filled with quartz by the ascending currents from deep-seated sources. In like manner the cavities and druses found in the petrified trees of the fossil forests are lined with quartz crystals, due to heated siliceous waters coming up from below. Today there are no hot springs or steam vents to be found in the Absarokas, save in a feeble way on the western flanks, where the ancient breccias have been penetrated by much later rhyolites.

It has seemed necessary to present this somewhat lengthy description of volcanic forces existing in Miocene time in order to bring out in strong contrast the conditions prevailing during Pliocene and recent times.

Pliocene Igneous Rocks and thermal Waters

After the pouring out of the basic breccias and lavas of the Miocene, volcanic energy, for a time at least, ceased. Atmospheric agencies removed a large body of the surface rocks and carved out drainage channels in the easily disintegrated material. Following a prolonged interval of comparative rest came renewed activity, with marked changes in the nature of the eruptive lavas. Vast masses of rhyolite were extruded, not on preexisting mountains, but over an inclosed basin, converting it into a rugged tableland and submerging the flanks of the bordering ranges. This sharply defined region has been designated as the Park Plateau. It embraces a tract of country 50 by 40 miles, including approximately 2,000 square miles. Strictly speaking, it is not a plateau in the general acceptation of the word, but presents a broken surface accentuated by bold escarpments and abrupt slopes of lava flows. While the topography of the tableland has, to some extent, been modified since Pleistocene time and trenched by ice action, giving the effect of individual plateau blocks, the mass can not be considered otherwise than as a geological unit. The earliest rhyolitic eruptions spread over a very uneven surface, the structural features of which may be fairly well inferred from exposures of sedimentary rocks rising through the surrounding lavas or cropping out from beneath the outer boundaries of the plateau. The rhyolite also lies unconformably on the eroded surfaces of Miocene basic breccias, and not infrequently occupies the older valley bottoms, clearly showing the much later age of the siliceous lavas. Although sharply defined by topographic relief and geological sequence, both periods of ejection are still more

strongly contrasted by marked differences in the phases of eruption which built up the two volcanic regions.

On the rhyolite plateau there are no evidences of violent explosive action. The complete absence of true volcanic breccias is a significant feature of these later flows. Dikes, veins, and horizontal sills, together with nearly all the phenomena of deep-seated intrusions, are wanting. The rhyolite shows scarcely any indications of hydrothermal activity during eruption. In the abrupt escarpments made up of successive sheets there are no signs of surface flows having been exposed to long-continued atmospheric agencies, no wind-strewn ashes, or any vestiges of vegetation. On the contrary, everything clearly indicates a relatively rapid accumulation of viscous masses from the beginning to the end of the rhyolite period. What impresses one most is the absence of stages of activity, with intervals of quiescence, there being rather a series of massive eruptions piled up one on another. In the central portion of the park the rhyolites have a maximum thickness of 2,000 feet, and over large areas they may be assumed to measure 1,500 feet.

Subsequent to the rhyolites and the building up of the Park Plateau came a few dikes and thin sheets of basalt. They are the most easterly occurrence of those broad basaltic flows that spread over southern Idaho and the Snake River plain. In the park country they are of Pliocene age—that is to say, they are older than the glacial ice. They make the final chapter in the history of Tertiary igneous rocks. As they play no recognized part in the problems bearing on thermal waters, they may be dismissed at the present time with this brief mention.

Unquestionably the Pleistocene age, with its changed conditions, set in not long after the dying out of rhyolitic eruptions, as is shown by the relatively slight erosion of the plateau and the beginning of canyon sculpturing. All geological evidence tends to prove that the rhyolites belong to the Pliocene age.

Duration of thermal Activity

That the activity of thermal waters was approximately coincident with the cessation of rhyolite ejections is, fortunately, clearly proven by the massive horizontal beds of calcium carbonate laid down on the summit of Terrace Mountain, where they attain a maximum thickness of nearly 250 feet, although the average is much less. Without doubt they are the oldest deposits of travertine in the region of Mammoth Hot Springs, and rest directly on fresh, unaltered rhyolite. Glacial ice from the Gallatin Mountains moving eastward occupied the intervening Swan Lake Valley and passed over the top of Terrace Mountain on its way to the broad,

open valley of the Yellowstone. On the recession of the glacier fragments of crystalline rocks, undoubtedly brought down from the Gallatin country, were left strewn over the travertine of Terrace Mountain.

It is a fair assumption that if these thermal waters were issuing through rhyolite at one locality in pre-Glacial time, similar hot waters and gaseous emanations should have reached the surface at other points on the plateau. If any such remnants of sinters still remain it seems impossible, from our present knowledge, to discriminate between them and those of post-Glacial time. Erosion has carried away not only every trace of these earlier deposits, but has removed nearly all evidences of pre-Glacial rock decomposition. Modifications in topographical relief fail to indicate two distinct periods, owing probably to the relatively slight deposition of sinter before the ice.

Following the withdrawal of a broad ice-sheet, ascending heated waters, acting with renewed energy on the walls of innumerable fissures and rifts, bleached and kaolinized massive blocks of rock. This decomposition of plateau lavas proceeded on a grand scale and left an indelible impression on the rhyolite area. In regard to the age of the hot springs, it is reasonable to conclude that thermal waters were as active at the close of the rhyolite extrusions as at any subsequent period. The antiquity of many localities of decomposed rhyolite is clearly evident, as shown by post-Glacial sculpturing. In certain areas where hydrothermal energy was formerly a long-continued process, evidence of the presence of such sources of heat have long since ceased. No one who has studied the gradual development of these decompositions and metasomatic changes under the influence of acid solfataras, or the deposition of sinter now taking place from alkaline siliceous waters, can doubt the lapse of time required by these geological agents to accomplish the results observed. Such processes can not, however, differ essentially other than in degree from those observed today. In my opinion, they have never ceased to be active and have only varied in intensity from time to time. It meets all the requirements, therefore, for our present purpose, to consider the phenomena now taking place, or since the hot springs and geysers were first brought to the attention of the scientific world, about forty years ago.

Climatic Conditions

Precipitation of moisture over the plateau and encircling mountains is far heavier than that taking place over the semi-arid regions below. Not only is the rainfall higher for every month of the year, but the temperature is correspondingly lower. Four large rivers—the Yellowstone,

Snake, Madison, and Gallatin—carry the waters from the uplands to the lowlands. Knowing the amount of water leaving the park by these principal drainage channels, it is easy to estimate approximately the total amount of surface waters carried away.

Meteorological records, more or less complete, have been kept at Mammoth Hot Springs for over a quarter of a century, and during one winter at the Firehole Basin. From these data an approximate estimate can be made of the water falling over the entire region. Some years ago instrumental measurements were undertaken during the summer to determine the amount of evaporation on the open sinter plain in the Upper Geyser Basin. Similar observations were made at the outlet of Yellowstone Lake. Taking into consideration the annual precipitation and run-off and the summer evaporation, I believe the supply of water greatly exceeds the amount carried away by surface streams. Climatic conditions, as they exist in the park today, favor forest development and a varied undergrowth. It is estimated that over 82 per cent of the region is forest-covered. For eight months precipitation occurs in the form of snow, which, protected by the forests from the sun's rays and the drying winds, melts slowly and lingers on well into midsummer. On the adjoining mountains the snow seldom entirely disappears. The retention of the water by forest and undergrowth brings about the development of the many meadows, marshes, and bogs. Scattered over the tableland occur frequent ponds and lakelets, carrying in the aggregate a very considerable body of water. In this connection may be mentioned such large reservoirs as Yellowstone Lake, covering over 125 square miles of surface, and Shoshone Lake, measuring 12 square miles, to say nothing of other picturesque sheets of water of less imposing dimensions, all of which lie on the rhyolite from 500 to 700 feet above the Upper Geyser Basin, where the greatest number of large geysers is found and the activity and overflow of thermal waters displayed on a grand scale. In time much of the water from the meadows and ponds naturally finds its way to surface streams. Another portion is taken up by the luxuriant vegetation or is absorbed by the atmosphere. The remaining water, which constitutes a very considerable volume, is drawn down through openings into underground reservoirs. In other words, these descending waters slowly percolate through the viscous lavas.

Physical Structure of Rhyolite

Returning for a few brief moments to rhyolite flows, let us consider certain physical features due to textural modifications. No region sur-

passes the Yellowstone Park in the varied phenomena of highly acid extrusions. This is especially true of the more glassy types, and in general a glassy groundmass characterizes most of these lava sheets. Mr. J. P. Iddings has submitted a large series of specimens of the park rhyolites to a searching petrographical investigation, making a special study of the microgranular structure and the relations of the different microstructures to one another, and pointing out the abrupt transitions from the glassy to the crystalline and from the pumiceous to lithoidal forms. For further details the student is referred to this admirable work. In conclusion, Mr. Iddings calls attention to the agency of water in bringing about the varied products. He says: "The heterogeneity of the acid lavas, so far as known, is confined to the distribution of vapors, presumably of water, and suggests that the water thus irregularly disseminated has not existed within the magma long enough to become uniformly diffused. It must therefore be looked upon as water absorbed near the earth's surface." [3]

From the point of view of the present discussion, the cause of these remarkable structural variations concerns us less than the influence exerted by such textural modification in the creation of fissures, fractures, and capillary openings for the percolation of waters. Obsidians, perlites, and pitchstones were poured out over the greater part of the central plateau and may be found at the base of bold escarpments under accumulation of successive flows. Glassy forms present as marked a feature of many of these earlier outpourings as they do of the more recent flows. They were surface flows when ejected. They prove conclusively, on geological evidence, that similar physical conditions were identical from the beginning to the close of the rhyolite phase of eruption. The liquidity of the magma and its crystallization change from time to time, being dependent on varying causes, such as the degree of temperature when ejected from the point of discharge, the volume of the mass, and the power of the lava to hold its contained heat.

Banded and laminated lavas, contact surfaces between magmas of different physical properties, shrinkage cracks and jointings in obsidian and perlite, overlapping of lava flows, all caused numerous capillary spaces in the rock. Some of these openings for short distances lie parallel with the lava flows; others are vertical along planes of jointing, while still others indicate great irregularity, broadening and contracting along a circuitous course. Uniting below the surface they develop into wider channels, affording free circulation of either descending or ascending waters.

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[3] J. P. Iddings: Geology of the Yellowstone National Park. Monograph XXXII, part II, p. 425.

Mineral and chemical Composition of Rhyolite

As I hope to be able to show that the mineral matter brought to the surface in solution by ascending thermal waters circulating through rhyolite is mainly derived from these lavas, it is necessary to examine in detail both their chemical and mineral composition. The chemical composition of the rhyolite appears remarkably uniform when the enormous bulk is considered and the different physical conditions under which the lava streams were extravasated.

In the subjoined table will be found analyses of eleven specimens of rhyolite, arranged according to their tenure of silica. They were made in the laboratory of the United States Geological Survey, but are here brought together in tabular form.

In five analyses the range in silica falls within seven-tenths of one per cent. Lime and magnesia show the greatest variation, while the alkalies do not appear to be higher than in many other localities where rhyolite has been extravasated in the form of massive eruptions. Titanic oxide has been determined in small amounts, but was not detected in the obsidians or in any of the extreme glassy rocks. On the other hand, both sulphuric acid and chlorine occur in small quantities in the fresh glassy varieties, but, curiously, analysis fails to show the presence of both in the same flow. Traces of manganese have been detected in many specimens from widely separated parts of the tableland, which is interesting from the fact that in one or two localities solfataras have deposited manganese oxide as dendritic incrustations. Considering the rhyolite as a homogeneous mass, the composition of the molten magma is probably best shown in the specimen from Madison Canyon. Here the silica percentage was 75.2 per cent, the alumina 13.77, and the combined potash and soda 7.16.

As regards mineral composition the rhyolite is by no means as simple; owing to textural modifications that range from semitransparent, amorphous obsidian, to liparite, with relatively little groundmass. Nevertheless, the species that have crystallized out from the magma are few in number, the only essential rock-making minerals being quartz and sanidine. In certain lavas quartz, in irregular crystals, occurs abundantly disseminated as megascopic phenocrysts, while in others it is wholly wanting. Plagioclase stands next in order, being easily recognized in many thin sections under the microscope, although being seldom recognized by the naked eye. This is probably owing to the small amount of alkaline earths present. Small flakes of biotite have been detected here and there, but in the typical rhyolite it may be said to be absent. Pyroxenic minerals are rare and only in microscopic crystals. Magnetite is

Analyses of Rhyolites from Yellowstone National Park.

Group.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO
I. Upper Geyser Basin	70.92	.16	13.24	3.54	.66	.14	.23	1.42
II. Head of Tower Creek	71.85	.43	13.17	2.17	1.34	.12	.63	2.25
III. Plateau east of Willow Park	72.59	.52	13.47	1.58	1.32	Trace	1.05	2.12
IV. Cliff east of Excelsior Geyser	73.84	......	12 47	.32	.90	Trace	.25	1.08
V. Obsidian Cliff	74.70	None	13.72	1.01	.62	Trace	.14	.78
VI. North Madison Plateau	75.19	None	13.77	.61	1.37	Trace	.09	.68
VII. Elephant's Back	75.34	None	12 51	.42	1.55	.07	.32	1.07
VIII. Obsidian Cliff	75.50	None	13.25	1 02	.91	None	.07	.90
IX. Obsidian Cliff	75.52	None	14.11	1.74	.08	None	.10	.78
X. Sheridan Volcano	75.89	.50	12.27	1.12	1.37	None	.29	.86
XI. Sherman Volcano	77.65	.14	11.50	1.21	.26	None	....	.59

Group.	Na_2O	K_2O	Li_2O	P_2O_5	SO_3	H_2O	Cl	Total.
I. Upper Geyser Basin	4.28	4.25	.	.18	....	.57	....	99.59
II. Head of Tower Creek	4.06	3.89	.	.14	....	.43	....	100.48
III. Plateau east of Willow Park	4.63	2.52	.	None	....	.18	....	99.98
IV. Cliff east of Excelsior Geyser	2.88	5.38	.	....	....	2.76	....	99.88
V. Obsidian Cliff.	3.90	4.02	.	None	....	.62	.40	100.31
VI. North Madison Plateau	3.83	3.33	.02	None	.29	.65	....	99.83
VII. Elephant's Back	3.31	4.17	Trace	None	.42	.86	....	100.04
VIII. Obsidian Cliff	4.76	2.85	.06	None	.32	.41	....	100.05
IX. Obsidian Cliff	3.92	3.63	....	None	....	.39	.11	100.49
X. Sheridan Volcano	3.23	3.42	.01	None	.28	.82	....	100.06
XI. Sherman Volcano	3.33	4.85	....	.02	....	.28	....	99.84

somewhat more widely distributed, but only in minute grains, as might be supposed from the low percentage of iron oxides. The presence of titanium in the magma reveals itself in the disseminated grains of ilmenite and pseudobrookite. Apatite, zircon, and allanite complete the limited list of accessory minerals.

Classification and Composition of thermal Springs

The number of springs scattered over the park, from which flow varying amounts of thermal waters, probably exceed twenty-five hundred. If to these be added the fumaroles, solfataras, and narrow rifts, from which issue steam and gaseous emanations, mingled with more or less water, the number would be greatly augmented. It is impossible to enumerate them, as new ones are frequently reaching the surface, while others are slowly becoming extinct. Furthermore, it would be no easy task to decide whether single points of discharge should be counted or considered as a group having a common source a short distance below ground. These thermal waters reach the surface holding mineral matter in solution, derived from the decomposition of rocks through which they pass in their upward movement. They may be arranged under four heads:

1. Waters carrying calcic carbonate in solution.
2. Siliceous alkaline waters rich in dissolved silica.
3. Calcic siliceous waters having both properties of calcic carbonate and siliceous alkaline springs.
4. Siliceous acid waters, usually holding free acid in solution.

Nearly thirty of these thermal waters have been analyzed by F. E. Gooch and J. E. Whitfield in the laboratory of the United States Geological Survey and the results published in a separate bulletin.[4]

Among these waters are several from the Mammoth Hot Springs characterized by the large amount of calcic carbonate in solution, associated with free carbon dioxide and sulphates of magnesium and the alkalies. Underground conditions were doubtless favorable for holding in solution large amounts of calcic carbonate. With the relief of pressure at the surface and the diffusion of free carbon dioxide, precipitation followed, as shown in the deposits which have made the Mammoth Hot Springs so famous. From the present point of view we are not so much concerned with depositions from these waters as with the waters themselves and their geological relations, since they unquestionably have a common source with those of the rhyolite plateau.

At the Mammoth Hot Springs the upper lava flows lie directly against

[4] F. A. Gooch and J. E. Whitfield: Analyses of waters of Yellowstone National Park. Bulletin of the U. S. Geological Survey, No. 47, Washington.

inclined Jurassic limestones. The circulating hot waters having been diverted in their course traverse the limestone before issuing at the surface. Apparently the waters derive a large part of their mineral constituents from the limestone. In contrast to the hot waters of the plateaus they carry but little silica in solution. Far to the southward, where the rhyolite tableland ends, the attenuated lava streams also rest against uplifted limestones. Calcic carbonate springs, although of modest dimension, issue through the rhyolite, but have derived their mineral contents mainly from the adjacent limestones. Both the carbonated waters and the travertine deposits resemble those at Mammoth Hot Springs. Similar geological relations may be observed near the eastern limits of the rhyolite at Soda Butte Spring, and again near the western border.

On the other hand, wherever the heated waters issue from the rhyolite of the tableland they are characterized by a high percentage of silica. These waters occur distributed over a wide area and furnish the great volume of water discharged from the geysers and hot springs, and for this reason have excited more general interest than the smaller springs. They have supplied the silica for the many square miles of glittering white sinter plains. For the most part they are siliceous alkaline waters, as in the Upper Geyser Basin and the Firehole Basin. They, however, may be slightly acid or neutral, as in the case of many of them in Norris Basin.

The silica occurs in solution as hydrated silica associated with carbonates and chlorides of the alkalies, together with small quantities of sulphates. Arsenic and boron have been determined in nearly all geyser waters, probably combined with soda as arsenates and borates. Traces of bromine, phosphoric acid, soda, manganese, lithium, caesium, and rubidium were detected in several instances, but lithium and bromine are the only elements present in sufficient quantities to allow of estimation. Tests were made for titanic acid, nitric acid, iodine, fluorine, barium, and strontium, but none of them were found. Special examinations were made in concentrated solution for tin, copper, and lead, but no one of them was present. In this connection it may be pointed out that while veins carrying lead, copper, and silver are found associated with Eocene and Miocene igneous rocks, these metals have never been detected in either the rhyolite or waters of the park.

A study of these chemical analyses brings out clearly the marked differences in percentages of substances held in solution, especially silica, even in adjoining geysers. This holds equally well for the siliceous alkaline waters from the same geyser basin as from those collected from different localities. Waters examined the same year show as great variations as those collected one or two years apart. The silica, as determined by

analysis, ranges from .22 to .67 grams per kilogram of water, the former being the amount found in the cauldron of the Excelsior, having the largest outflow of any pool in the park, and the latter from Opal Spring in Norris Basin, with but slight run-off and without any apparent inflow. The cause of these differences is, I believe, to be sought in the varying amounts of infiltrating surface water.

Dr. W. H. Hallock has shown conclusively, by experimental tests with self-registering thermometers, that the thermal waters stored in underground geyser reservoirs possess a temperature far in excess of the boiling point at the surface, due to increased pressure of the overlying column of water in the geyser tube. The results were in accord with the theoretical boiling point. It can not be affirmed positively that these superheated waters maintain the same composition after being thrown out as the underground waters at greater or less depth or even with those of the geyser reservoirs. On the other hand, there exists no evidence of chemical changes due to relief of pressure before the waters reach the surface through geyser orifices.

On the relief of pressure, hydrated silica, associated with traces of an equally insoluble silicate of alumina and lime, is deposited on the broad plains of the geyser basins. Nearly all remaining constituents are carried away in solution by surface streams. Although the composition of the deposited sediment is everywhere much the same, its external habit varies with the manner of its secretion, which may have happened in several ways. It may have been caused by precipitation on relief of pressure, precipitation on cooling, separation by evaporation, and assimilation by algæ. Mr. Walter H. Weed has shown conclusively the important part such organisms perform as geological agents in the accumulation of sinter deposits.[5]

The volume of siliceous alkaline waters far exceeds those of the acid type. On the other hand, the latter occur more widely distributed, are more complex in their composition, and consequently more varied in their deposits. These acid waters come to the surface through fumaroles, solfataras, and the so-called mud springs and paint pots. In nearly all such occurrences the waters carry either free hydrochloric or sulphuric acid. In general these thermal waters, which rise through narrow seams and rifts, run but little water and leave behind only thin incrustations around the sources of supply. These deposits are found widespread over the park and consist principally of sulphates of alumina and double compounds of alumina and iron. While they show a mingling of saline

[5] Walter H. Weed: Formation of travertine and siliceous sinter by the vegetation of hot springs. U. S. Geological Survey, Ninth Annual Report, Washington, 1890.

compounds carrying more or less silica as an impurity, the number of mineral species remains singularly few. Halotrichite, alunogen, and alum are the only minerals of the alum group determined. In the far more arid regions of New Mexico accumulations of these minerals have been described by Dr. C. W. Hayes[6] as deposits from aqueous solutions associated with igneous rocks.

Under quite different conditions, and as thin layers deposited below water level in the Norris Basin, occur incrustations of both sulphides of arsenic, orpiment and realgar. They are, however, very restricted in quantity. Scorodite, delicate crystals of sulphur, and ochreous deposits, mainly ferric oxide and silica, are characteristic of certain acid and neutral waters. These sediments and incrustations point clearly to different conditions of thermal activity. In strong contrast from those described in connection with siliceous alkaline waters, they indicate an earlier stage in the development of rock decomposition.

Gases from thermal Springs

Several years ago gases emitted from many of the springs were collected and submitted to analysis by Prof. F. C. Phillips, of Pittsburg. They were all found to carry carbon dioxide, oxygen, hydrogen, and nitrogen, but to vary greatly in relative amounts. In general, those from Mammoth Hot Springs, where the waters issue through limestones, are characterized by carbon dioxide, one analysis from the spring on the main terrace holding no less than 98.68 per cent of the gas. Those from the upper basin, which issue directly from the rhyolite, consist principally of nitrogen, the Artemesia Geyser carrying 95.08 per cent of the latter gas. Traces of methane were found in several waters. Hydrogen sulphide was only detected in two samples, and in neither of these did the gas amount to one per cent of the gaseous content. One of these was from a sulphur spring in the Mammoth Hot Spring Basin and the other from the Shoshone Geyser Basin. In none of the waters from the geysers and large hot springs in the three principal basins was any hydrogen sulphide detected.

Professor Phillips says: "There is, in fact, a curious gradation between analyses from No. 1 and No. 10, as regards the proportion of nitrogen and carbon dioxide. Oxygen is present in all of them, and as ten of these gases contain combustible elements, hydrogen and methane, it is evident that the gas as it escapes from the spring has not been exposed to a high temperature."

It is admitted by most authors that under certain conditions all these

[6] Dr. C. W. Hayes: Bulletin of the U. S. Geological Survey, No. 315, 1905, pp. 215-223.

gases may be contained in surface waters. I think it has been shown that under the peculiar conditions in which these waters occur and their lack of uniformity of composition they must be considered as absorbed by vadose waters.

One of the most marked characteristics and one of geological significance is the frequent variation shown in temperature, flow, and salinity of the thermal waters where they issue from the rhyolite plateau. The solvent power of water holding mineral matter in solution is, as is well known, far greater than that of pure water. Now the downward percolating waters gather material from the disintegrated rhyolite soil and in some measure from the soluble salts previously brought up from below. There is also a certain amount of carbon dioxide derived from the atmosphere. It is a fair assumption, therefore, that in percolating downward the waters carry with them to the water level below no inconsiderable amount of material.

The ascending superheated waters, under pressure, exert a far greater influence. The work done by these waters, and that which is still going on, is self-evident even to the most casual tourist. It is shown by the broad areas and ridges of altered and bleached rhyolite. Nowhere is this more in evidence than in the escarpments along the Grand Canyon of the Yellowstone, where the gorgeous coloring is due to the oxidation of the ferruginous minerals. The potent influence of such waters under existing conditions can hardly be questioned. They readily attack both the glassy groundmass and crystalline feldspars of the rhyolite, and when the metasomatic changes are complete they leave behind an impure kaolinized material mixed with quartz and held together by colloidal silica.

Development of Springs and Geysers

The ascending waters, in their circuitous course, penetrate fresh seams and cracks in unaltered rock, which slowly widen under the disintegrating influences of aqueous vapors. Finally the thermal waters, following these cracks, issue at the surface as hot springs and pools. The early waters are usually acid in composition and deposit ferric and aluminous salts. Occasionally they set free sulphur, derived from the decomposition of hydrogen sulphide. In time the openings through which they flow become broader, the waters themselves, free from hydrogen sulphide, become clearer and neutral, and at last issue as siliceous alkaline waters. Underground reservoirs are excavated and become sources of hot springs and, under favorable conditions, geysers. The geyser itself is simply a stage in the development of geological processes. In time geysers themselves become extinct. New geysers break out and, given the essential physical conditions, may develop eruptions quite as fine as any in action

at the present time. Geologically speaking, the final stage of thermal activity is a hot spring. The tendency of a geyser is to develop a hot surface pool. If from such pools there is discharged a sufficient amount of overflow, and if from the surface of these geyser pools there is an ample dissipation of heat into the surrounding atmosphere, explosive action may cease and the geyser, as such, may become extinct. It is frequently stated that some geyser has ceased to be active, and that this indicates the slow dissipation of the original source of heat. This I believe to be an error. The change is simply due to a shifting of the channel of the ascending waters.

If, on the other hand, there should be marked climatic changes and arid conditions should set in over the park and adjoining mountains, in my opinion, thermal springs would become extinct. Should this happen it would be evident beyond all question that the waters were derived from vadose sources. Again, with the disintegration of lavas and the building up and enlargement of reservoirs, existing conditions of hydrostatic pressure would cease and the circulating waters, unable to rise, would distribute themselves laterally; in which case there might break out at the base of the rhyolite plateau calcic springs such as we now find and have already described.

In all probability the magnitude of a geyser is, in a measure, dependent on the size of the underground reservoir, or series of reservoirs, produced by the disintegration of lavas along channels of ascending waters. It has been demonstrated by self-registering thermometers that cool infiltrating waters may drain into partially erupted reservoirs after geyser eruption. This has been shown in the case of the Giantess Geyser. The question was once asked by an attendant at the hotel, who had spent several summers in the park, why Old Faithful was more apt to be several minutes behind time in September than in July. I am not aware that such a condition was ever established, but if so, my reply would be that in the autumn the infiltration of surface waters is not as rapid as in early summer; hence a retarding of the eruption by several minutes.

It is probable that the Norris Geyser Basin, in its thermal development, is later than the Upper Geyser Basin. In the former are found the early and more acid conditions; the waters of the geysers are mainly neutral and form deposits of arsenical sulphides, alum, and ferric salts. These phenomena are for the most part absent in the Upper Geyser Basin, where the waters have reached a more advanced stage and possess a siliceous alkaline composition.

With the exception of arsenic and boron, which occur in minute quantities, all the elements brought to the surface in solution by the thermal waters of the park have been found in the rhyolite. In this connection

it may be said, and it is generally accepted by those who have studied the region, that the mineral waters of Pfaeffers, in the Tyrol, have a vadose origin, and analyses show that both these elements are present.[7] Both these elements are found associated together in many thermal waters of Europe. Not only is it true that, with these exceptions, all the elements are accounted for in the rocks, but the proportion of the ingredients in the waters bears a remarkable relation to that of the elements in the rhyolite itself. Silica and the alkalies are the predominating elements. Even lithia, which is a feature of many siliceous lavas, has been quantitatively estimated in all these thermal waters. The water from Old Faithful yielded .0056 of a gram per kilogram of water, which, according to the theoretical composition, shows that lithium chloride forms 2.44 per cent of the amount of material held in solution. The neighboring Giantess Geyser carried precisely the same amount of lithium chloride. The low percentage of iron, manganese, lime, and magnesia contained in the ascending waters is readily accounted for by the comparatively small quantities of these elements in the glassy rhyolite through which these waters pass.

The circulating ascending waters may, to some extent, be charged by foreign substances other than by superheated aqueous vapors. Nevertheless, in the park country the vadose ascending waters do not appear to have been greatly affected by any primitive, deep-seated waters or their contents. Even if foreign mineral matter were present it does not follow that the material was not taken up originally by vadose waters.

In Iceland geological conditions are apparently quite different, and volcanic eruptions may be said, geologically speaking, to be still going on, in strong contrast to the Yellowstone Park, where such action ceased many thousand years ago. In Iceland the thermal waters are, in my opinion, mainly vadose, and their heat derived from sources not far below the surface.[8]

I agree with Dr. Rudolf Delkeskamp[9] that temperature, included gases, and salinity in many localities are not in themselves conclusive evidence of the source of thermal waters, and that far safer criteria for the determination of the primitive origin of waters are to be sought in uniformity of flow and chemical composition. What I wish to emphasize, however, is that the thermal waters of the Yellowstone National Park are charac-

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[7] M. De Launay: Annales des Mines, February, 1894.

[8] Since presenting this address I have received from Dr. Thorkell Thorkelsson, of Copenhagen, a copy of a suggestive paper on "The hot springs of Iceland," which confirms me in the opinion of the vadose origin of the Iceland thermal waters. Dr. Thorkell's paper appears as a recent publication forming one of the Memoires de l'Academie Royale des Sciences et des Lettres de Danemark. Copenhague, 1910.

[9] Juvenile und vadose quellen, Balneologischen Zeitung, XVI, Jahrgang, No. 5, 1905.

terized by frequent variations of temperature, progressive transitions in chemical composition, lack of uniformity in mode of occurrence, and shifting in points of discharge; in other words, they lack the essential characters of primitive waters derived from deep-seated sources.

Radioactivity of thermal Waters

Throughout this paper in the discussion of the geological relations of the thermal waters to the rhyolite eruptions laboratory investigations bearing on the composition of the rocks, waters, sediments, and gases have been utilized. In the discussion of the circulation of descending and ascending waters almost nothing has been said in relation to the source of heat which raised the temperature of these waters. This is in part due to the fact that the problems involved are in a great measure distinct from those treated here, and time does not permit of their consideration, and in part because I know little about the matter. My opinions are still open to conviction. With this avowal I may be allowed to add that I am reluctant to believe that the source of the heated waters is, geologically speaking, deep seated or subcrustal.

In this connection it might not be out of place to mention the investigations of Prof. Herman Schlundt and R. B. Moore on the radioactivity of the thermal waters of Yellowstone National Park, conducted under the auspices of the United States Geological Survey and recently published.[10] They found the rhyolites, limestones, thermal waters, gases, and sediments to be radioactive. Specimens of rhyolite from widely separated localities in the park were examined. These authors say:

"These data certainly seem to indicate that the hydro-thermal activity so manifest in the park is not connected with localized deposits of radium. In the above calculations the question of heat lost by diffusion and other factors is not taken into consideration, but after allowing a generous margin for error we do not see how more than one per cent of the heat required for the hydro-thermal action can be ascribed to the radium content of the rocks."

Recently deposited travertine at the Mammoth Hot Springs, as well as that of the Main Terrace and from the preglacial capping on Terrace Mountain, was subjected to similar tests. The same authors say:

"The travertine of Terrace Mountain is overlain by glacial boulders. Since its activity is only one per cent of the recent deposits, its age is about 20,000 years, which would also be the approximate time that has elapsed since the glacial period in the park."

Furthermore, a sample of the Jurassic limestone underlying the Mammoth Hot Springs proved to be more radioactive than the most active

[10] The radioactivity of the thermal waters of the Yellowstone National Park. U. S. Geological Survey Bulletin, 1909, p. 395.

sedimentary rocks tested by that eminent authority, R. J. Strutt, of England. It is noteworthy that the latter rocks referred to were specimens of the oölite formation from near the celebrated springs of Bath.

Strutt has also pointed out that siliceous igneous rocks are more radioactive than basic lavas,[11] a highly significant observation when it is borne in mind that the rhyolite of the Yellowstone National Park stands preeminent as an acid, crystalline rock. Iddings and Cross[12] have shown that allanite in microscopic crystals is widely but sparsely distributed in the siliceous igneous rocks of the Rocky Mountains, and has been detected in the rhyolite of Yellowstone National Park. Now allanite is known to carry small quantities of thorium. It is a coincidence worthy of note that thorium emanation was determined in several of the hot pools, it being first observed in this country in thermal waters in an obscure hot spring in Norris Basin. I see no reason, however, to doubt the conclusions of Messrs. Schlundt and Moore that the heat produced by radioactive emanation from the rocks and waters is wholly inadequate to meet the requirements. It seems necessary, at least from our present knowledge, to look elsewhere for the source of the heat dissipated by the thermal waters of the Yellowstone Park.

Summary

In conclusion I may state that I have attempted to show: (1) that igneous activity was continued throughout Tertiary time; (2) that this activity came to an end with the close of Pliocene time; (3) that during the Eocene and Miocene deep-seated waters were active geological agents, and that these waters were essentially primitive in their origin; (4) that in strong contrast to the explosive, volcanic conditions of the Miocene, the Pliocene lavas were emitted under far quieter conditions and built up the successive flows that formed the rhyolite plateau; (5) that during the many thousand years since the withdrawal of glacial ice the Pliocene rhyolites have, since the beginning of Pleistocene time, been steadily undergoing progressive changes, brought about by the action of enormous volumes of superheated vadose waters; (6) that the gases contained in the thermal waters were in great measure derived from vadose sources; (7) that the eruptions and periodicity of geysers are phenomena due essentially to varying conditions of reservoirs and channels of superheated waters situated only short distances below the surface; (8) that the phenomena as seen today represent a phase in the evolution of thermal springs.

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[11] R. J. Strutt: On the distribution of radium in the earth's crust and on the earth's internal heat. Proceedings of the Royal Society, ser. A, vol. LXXVII, 1906, p. 479.

[12] Jos. P. Iddings and Whitman Cross: American Journal of Science, 3d ser., vol. 80, August, 1885, p. 108.

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REPEATING PATTERNS IN THE RELIEF AND IN THE STRUCTURE OF THE LAND[1]

BY WILLIAM HERBERT HOBBS

(*Presented extemporaneously before the Society December 27, 1910*)

CONTENTS

[1] Manuscript received by the Secretary of the Society December 29, 1910.

Relief Patterns in Landscapes

CHARACTER PROFILES

To the physiographer who has critically surveyed the relief forms of many districts with their manifold diversities in character of bedrock, in structure, and in physiographic history, there is much which may be read at the first glance. Perhaps first of all are noted those features of the landscape which disclose the stage in the geographic cycle through which the district is passing. There may be, further, distinguishing lines which reveal in one case the work of waves, in another of mountain glaciers or of a continental ice-sheet; again, it is a partial submergence of the land which is disclosed, or a moulding of the surface under arid conditions rather than the more familiar, if not more prevalent, denudational processes of a humid climate. In the more striking instances—with purer types—fault topography may be distinguished from fold topography (see figures 1 and 2), though these are often merged in one another. In Germany, at least, it is customary to differentiate table mountains ("Tafelgebirge") and fold mountains ("Faltengebirge") with their notably different relief characters.

The broader relief characteristics which have been referred to, may generally be read from the characteristic elemental lines that are usually many times repeated in the landscape. Thus there may occur a nearly horizontal line which is more or less abruptly continued downward in a line of marked steepness and which indicates a youthful erosional stage (*a*, of figure 3). Again it may be a gently flowing reversed curve—the Hogarthian line of beauty—which is peculiar to mature landscapes (*b*, of figure 3), or it may be that the upper portion of the Hogarthian line is abruptly extended in a horizontal section, as would be the case when a maturely eroded district has been depressed and partially submerged (*c*, of figure 3). In those cases in which a shore has been successively uplifted it is a long and gently sloping line which is abruptly joined to a steep and often vertical one (*d*, of figure 3). The steplike profile of table mountains differs from this in having a horizontal section combined with a broken steeper portion (*e*, of figure 3), whereas fold mountains are generally characterized by curving elements in an unsymmetrical combination (*f*, of figure 3). Wherever volcanic cones appear, a beautifully regular curve *concave* upward and resembling the sine curve will be discovered (*g*, of figure 3). If *mountain* glaciers have occupied an up-

land district, the characteristic profile is similar to the last, but rotated

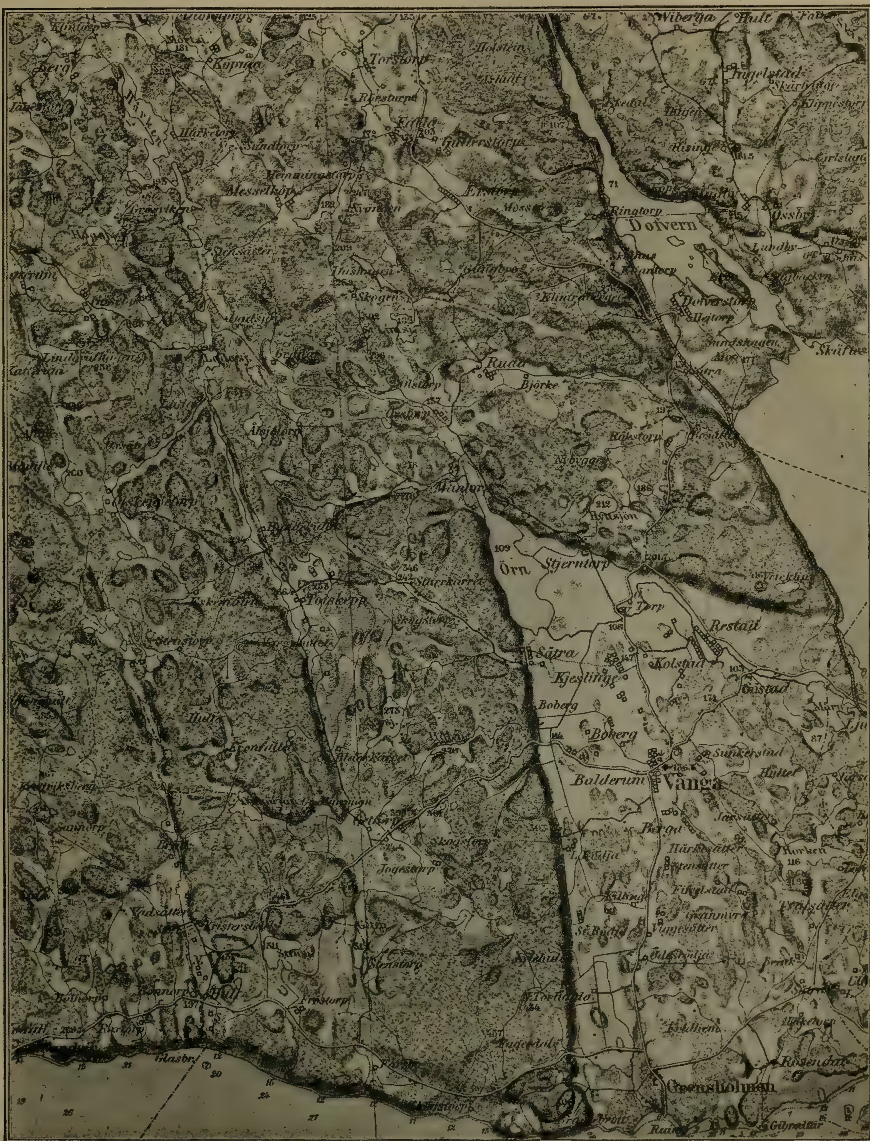

FIGURE 1.—*Typical Fault Topography*

The nearly straight elements should be especially noted. (From the Finspang sheet of the topographic map by the Swedish General Staff)

through 90 degrees, so that the straighter part of the curve is vertical instead of horizontal (*h*, of figure 3). Both the sculpture and the mould-

ing by *continental* glaciers yield, on the contrary, relatively gentle curves

FIGURE 2.—*Typical Fold Topography*

Note the curving zones of islands and the parallel water lanes which mark the courses of stronger and weaker rock layers respectively. (From the Vaxholm sheet of the topographic map by the Swedish General Staff.)

which are *convex* upward instead of concave and which are relatively symmetrical (*i*, of figure 3).

Such elemental lines in a landscape are the true profiles or their projections in perspective of the protruding portions of the lithosphere, and they may be referred to as *character profiles.* These profiles are the lines that would be selected by an artist in preparing an outline sketch of the landscape in pen and ink. Several of them may naturally be present together in greater or less perfection in the same landscape.

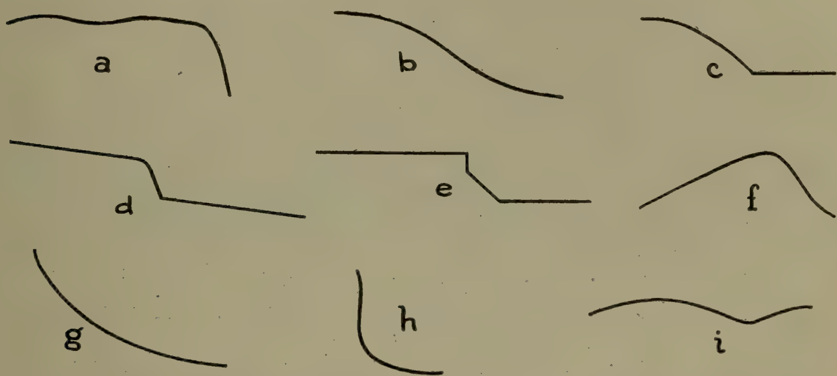

FIGURE 3.—*Some Lines of Profile each characteristic of a special Type of Landscape*

a, Dominant profile in a youthful erosional stage; *b*, the Hogarthian beauty line which recurs in mature landscapes; *c*, character profile of maturely eroded and partially submerged district; *d*, recurring element in profile of uplifted coast region; *e*, profile which recurs in table mountains; *f*, characteristic profile of fold mountains; *g*, profile line of volcanic cone; *h*, profile produced by mountain glaciation; *i*, the characteristic profile from continental glaciation.

SPACE UNITS IN PROFILES

The physiographer who has given special study to the profiles of many districts will further have noted a regularity in the recurrence of the elementary lines or a further subdivision of them. The larger notches in horizon lines are most of them waterways, at least during certain seasons, so that any regularity in their space relations will indicate a more or less uniform interval separating the lines in the drainage network. Such subequal spacing of streams has been often noted and by many observers. The late Professor Shaler believed that the mat of vegetation which covers the ground in humid regions largely interferes with a perfect expression of river spacing.[2] The importance of this factor was brought vividly home to the writer during a cruise along the west coast of Norway in the summer of 1910. The course of the steamer among the islands and skerries of the Norwegian coast offered unexcelled opportunities for

[2] N. S. Shaler: Spacing of rivers with reference to hypothesis of baseleveling. Bulletin of the Geological Society of America, vol. 10, 1899, pp. 263-276.

study of the dominant lines in the landscape, and at many places also of the structural elements of the nearer rock-masses. On this bleak, rocky coast there is little protection from vegetation, and the steep gradients of the surface keep the rock largely bare of mantle debris. Frost action is apparently the dominant weathering process—a process which always emphasizes the importance of planes of separation within the rock, since thus only can the prying stresses of freezing water be made effective. The conditions here are, therefore, ideal for a study of the influence of rock structure upon the relief forms.

DIFFERENT ORDERS OF SPACE UNITS

One whose attention was directed to the subject could hardly fail to notice that throughout the cruise the near profiles whenever visible indi-

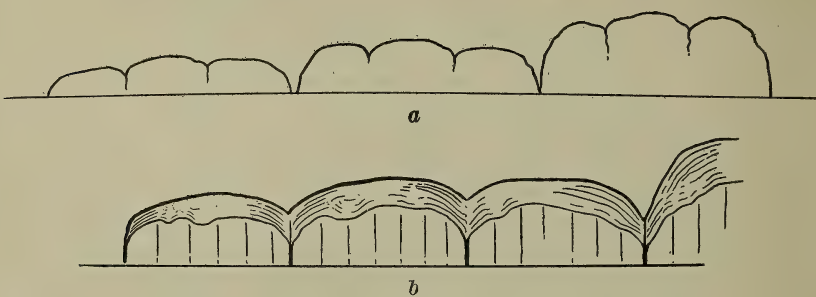

FIGURE 4.—*Illustrations from the Norwegian Coast*

a, Characteristic near profile on the Norwegian coast. There is a broader subdivision into nearly equal units, which are again subdivided into others of a lower order of magnitude. *b*, Diagram to illustrate the manner of subdivision of island profiles on Norwegian coast. Specially wide joints recurring at regular intervals permit of excessive frost work.

cated a quite remarkable subdivision into nearly equal spaces, which in turn were subdivided in a similar manner into smaller space units. The manner of this subdivision is schematically expressed in figure 4*a* and by photographs in plate 7.

The isolated islands not infrequently represent each a block unit of one or the other of the orders of magnitude described (plate 7, figure 2). Whenever the steamer approached the islands of the larger order particularly, it was possible to observe well developed vertical joints intersecting the cliff faces, with the crest of the island depressed at regular intervals in more or less sharply defined valleys which were each located above more midely gaping joints (see figure 4*b* and plate 7).

Joint intervals of a higher order of magnitude than those generally recognized are to be made out with especial clearness in figure 5, because

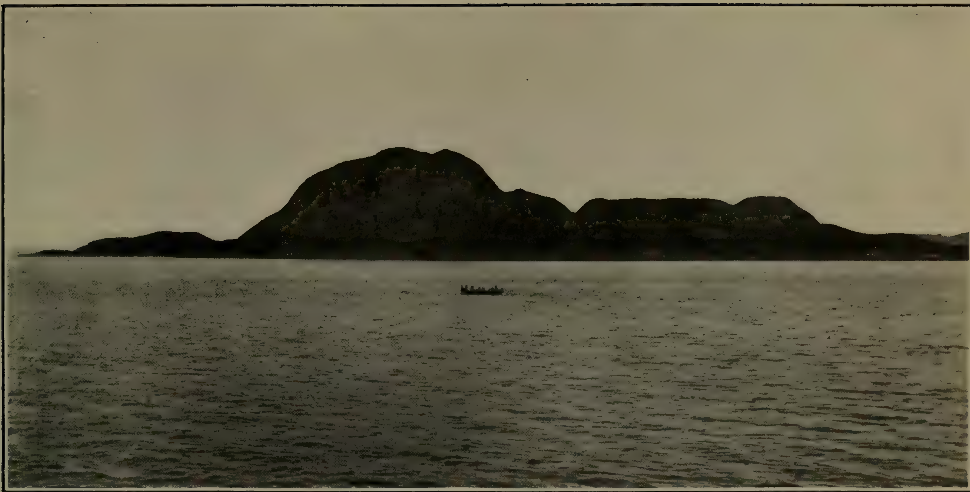

FIGURE 1.—CHARACTERISTIC PROFILE ON THE NORWEGIAN COAST

Showing a division into subequal space units of two orders of magnitude. Torghatten, Nordland. (After a photograph by Andvord)

FIGURE 2.—ISLAND GROUPS IN THE LOFOTEN ISLANDS OFF THE NORWEGIAN COAST

Showing repeating units of two orders of magnitude (in the middle distance). The distant mountains have been carved by late mountain glaciers and are less regular. (After a photograph by Knudsen, Bergen.)

REPEATING PATTERNS IN LANDSCAPES

Figure 1.—Beginnings of Erosion above a Series of Joints subequally Spaced. Spitzbergen
(After a photograph by Oscar Halldin, of Stockholm)

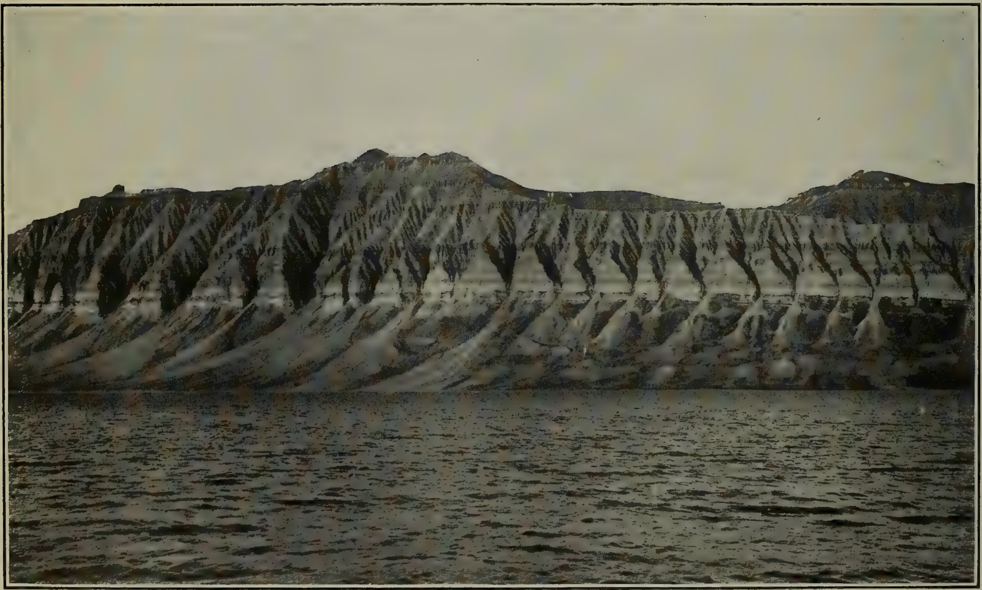

Figure 2.—Erosion Gullies in various Stages developing on an Escarpment above subequally spaced Joint Planes

Erosion somewhat more advanced than in figure 1. Spitzbergen. (After a photograph by Oscar Halldin, of Stockholm)

ROCK STRUCTURE BECOMING IMPRESSED UPON THE RELIEF THROUGH FROST ACTION

here the wind-blown snow fills the notchings of the surface at the joints.[3] When the cliffs seen on the Norwegian coast were too distant for examination of the joint system, the sags of the horizon line could still be seen to recur with noteworthy uniformity, except where obscured by the peculiar carving of mountain glaciers. From these observations it would appear that the subdivisions in the relief are determined, at least in part, by the concentration of frost work on the joints which show the widest

FIGURE 5.—*Effect of Frost Work*

The view shows the effect of frost work on joints with excessive weathering on more favored individuals which recur at subequal intervals. Collections of snow on deeper indentations display well the structure. (After a photograph from Iceland reproduced by Thoroddsen.)

openings, and that these recur at regular intervals. Such divisions of the country by joints of special importance being perceived along all azimuths, it is evident that a double series at least must be present, and that these are seen, first one and reciprocally the other, with varying amounts of foreshortening by perspective.

Relief Patterns in topographic Maps

CHECKERBOARD TOPOGRAPHY

The accurate maps of the coastal region of Norway show the relief to be ordered in a repeating pattern. Of the two orders of blocks above described, the units of the higher order are grouped to form unit blocks of still higher orders of magnitude (see figure 6). This striking large-

[3] Th. Thoroddsen: Lysing Islands (in the Icelandic language). Copenhagen, 1910, p. 255.

scale subdivision of the entire country, as is well known, was long ago pointed out by Kjerulf, who said:[4]

FIGURE 6.—*Subdivision of the Norwegian Coast Region*

The region is subdivided into blocks of a large order of magnitude (5 to 6 kilometers on a side), which blocks represent groups of several smaller units. The bounding lines here run northwest to southeast and northeast to southwest. (From the Björnör sheet of the official topographic map of Norway.)

[4] Th. Kjerulf: Geologie von Norwegen (authorized German edition by Gurlt). Cohen, Bonn, 1880, p. 332, fig. 279.

CHECKERBOARD TOPOGRAPHY

Repeating diaper pattern of rectangles due to a fracture system ordered on northeast-southwest and northwest-southeast lineaments. From the Elizabethtown quadrangle of the Adirondacks region by the U. S. Geological Survey.

"At many places on the west coast the land is cut up in the most striking manner into diamond-shaped areas by the coastline, the fjords and 'sounds' connected with it, or, if these are filled with sand, by the 'Eide.' Whoever has wandered through this region has required no map in order to recognize this impress upon the relief or the physiography of the landscape, since each section of the mountains stands cut off at an angle and separated from neighboring sections by a visible sunken area, almost after the manner of a wall with embrasures cut out."

Thus if one could view the surface of the country from a series of sufficiently high points, say from a moving balloon or from an aeroplane, there would be displayed a repeating pattern in the relief—the surface would be seen to be subdivided into similar compartments, as is a closely paneled wainscot. The term *checkerboard topography* was used by the writer in 1901 to describe such a repetition of a simple and regular diaper pattern in the relief of a district (see plate 9).[5] For the reasons already given, such patterns are apt to be especially distinct in high latitudes, where vegetable cover is scanty and where frost work is the dominant weathering process. On the basis of earlier studies, also, it may be stated that the characteristic relief pattern is one which not only repeats itself, but the same design is repeated in units of larger scale because of the grouping to form blocks of similar shape but of higher orders of magnitude. These, in turn, repeat in higher and still higher orders.[6] A similar grouping into larger units is brought out by Kjerulf's map of the larger lines in the relief of Norway (see figure 7).

THE PRIMARY UNIT OF THE SUBDIVISION

The lowest order of unit pattern may be conceived to be the individual joint block limited by consecutive joint planes in each of two or more series. Under exceptionally favorable circumstances, where there is no vegetable cover, these units may even appear in the relief of the country, because each is the locus of effective frost action. In western Greenland an illustration is found, and an embrasure-like notching of the coastline is also to be observed (see figure 8).[7] A grouping of the smallest units into blocks of six or eight thus appears to be indicated by the shoreline. Still larger groups are indicated upon a smaller scale map of the same

[5] The Newark system of the Pomperaug Valley. Twenty-first Annual Report of the U. S. Geological Survey, pt. iii, 1901, p. 150. See also Bulletin of the Geological Society of America, vol. 15, 1904, p. 500, pl. 47.

[6] Twenty-first Annual Report of the U. S. Geological Survey, pt. iii, 1901, pp. 104-121, pls. ix-xi, figs. 43-46; Bulletin of the Geological Society of America, vol. 15, 1904, pp. 500-506; Comptes Rendus 8me Cong. Géogr. Intern., 1906, pp. 193-202.

[7] A. Kornerup: Geologiska Iagttagelser fra Vestkysten af Grönland (66° 55′–68° 15′ N. Br.), Medd. om Grönl., vol. 2, 1879, pl. viii; résumé on pp. 180-181.

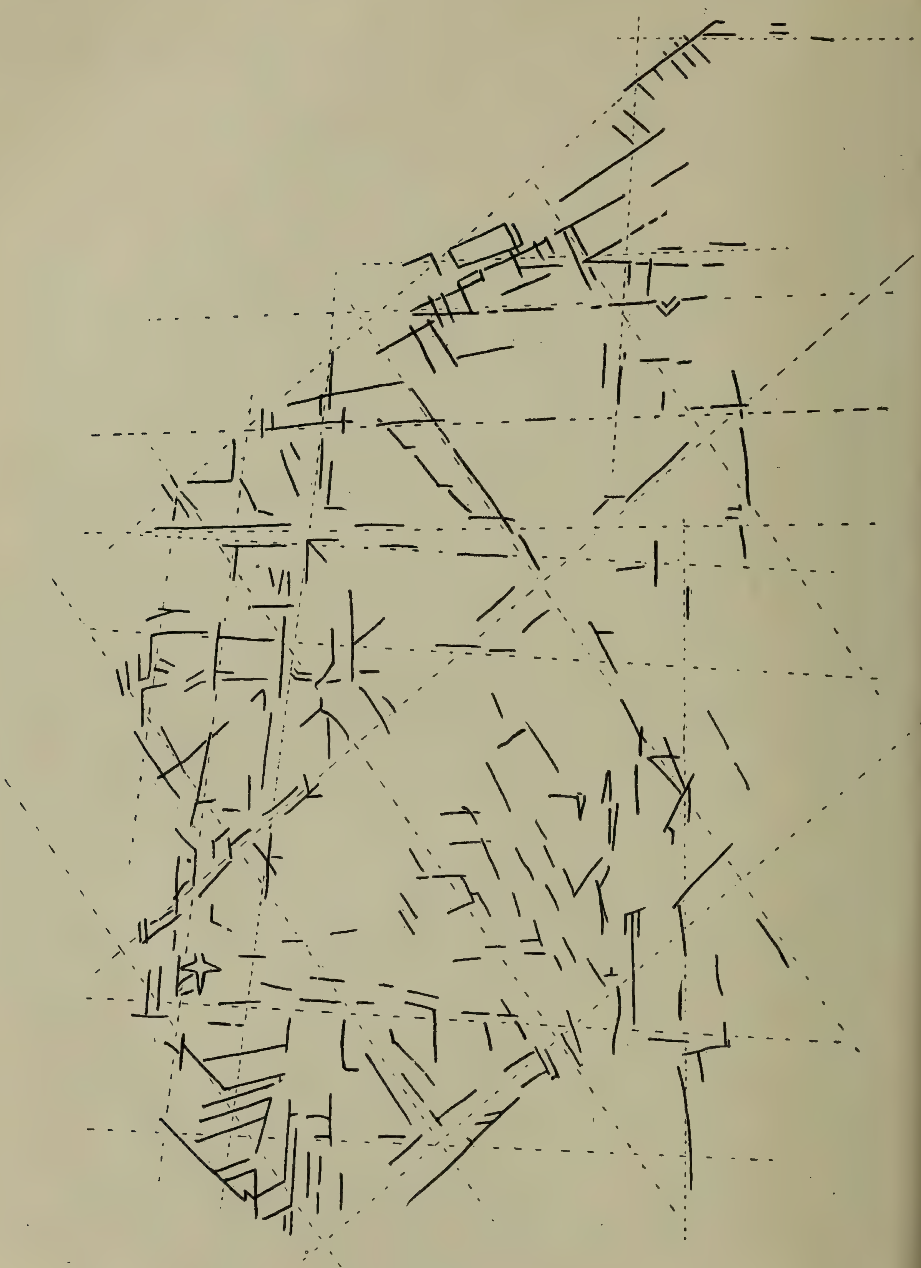

FIGURE 7.—*Kjerulf's Map of the Fracture System of Norway*

To this map faint dotted lines have been added, to emphasize the outlines of the larger space intervals which are indicated

coast region (see figure 9)[8] Speaking of the same coast of Greenland at a point some three degrees farther to the north, von Drygalski[9] shows how individual clefts in the rock can be seen to be widening by frost action and also extending their heads backward into the plateau. From this stage, he says, it is but a step to the formation of the long extended valleys, which, like the smaller ones, always leave upon one the impression of a long cleft.

FIGURE 8.—*Small Relief Unit determined by individual and consecutive Joints* Holstensborg, West Greenland. (After Kornerup)

DRAINAGE NETWORKS

NORMAL NETWORK IN ROCKS DEVOID OF STRUCTURE PLANES

The pattern of the relief as it is brought out upon maps is in large measure expressed in the drainage network. The normal pattern of this network upon an upland underlain by homogeneous rock which is devoid of structure planes, should be arborescent or branching like a tree. Just as the tree trunk and its branches usually fork so that branches and twigs point slantingly upward toward the sun, so the branches of the stream network are similarly inclined in the direction of the divide. Under these conditions there must be a normal angle of junction to which streams approximate (see figure 10). Such a normal arborescent drainage may be referred to as the normal drainage network for a maturely eroded district. The intricacy of the branchings—the scale of the de-

[8] A. Kornerup: Loc. cit., pl. vi, fig. viii, and pl. viii.
[9] E. von Drygalski: Grönland Expedition der Gesellschaft für Erdkunde zu Berlin 1891-1893, vol. 1, 1897, p. 37.

sign—will in a broad way be indicative of the precipitation of the district, the branchings showing wider space intervals in the less humid district.

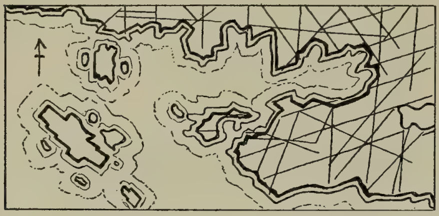

FIGURE 9.—*Embrasure-like Notching of the Coastline of West Greenland*

This notching is due to control by the fracture system of the district. (After Kornerup)

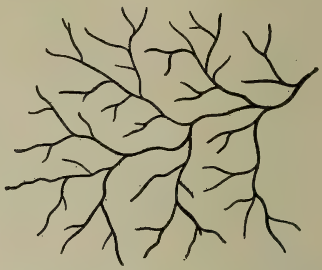

FIGURE 10.—*Normal Drainage Network above homogeneous Rock devoid of Structure Planes*

STRUCTURAL CONTROL OF NETWORKS

Variations from the normal network may be toward a largely lawless or haphazard system, such as may sometimes be seen in regions where rock is buried deep under drift deposits. On the other hand, a definite pattern in repeating diapers will be betrayed wherever the structure planes

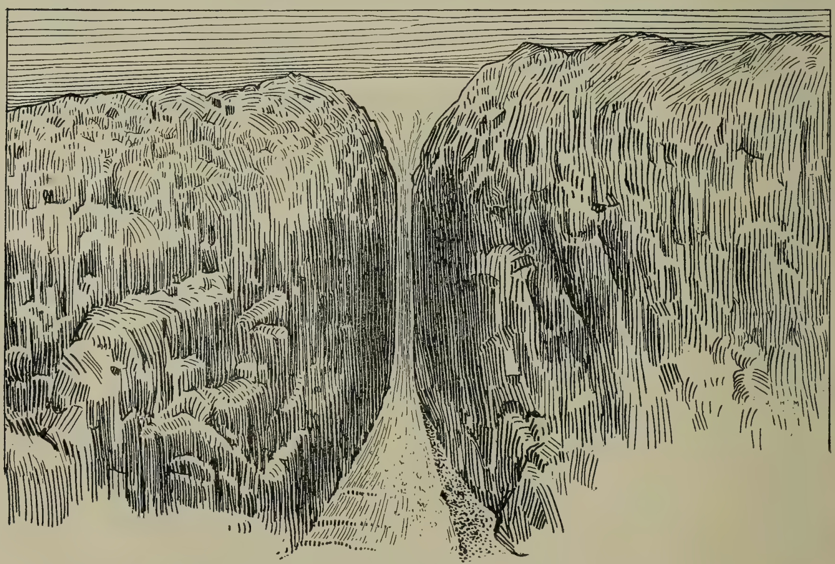

FIGURE 11.—*Illustration of structural Control of Network*

The view shows a narrow cleft in well jointed rock widened at top and bottom, within which talus is being removed by an outlet glacier, and the cleft extended headward by the same influence. East wall of the Sermiarsut glacier. (After von Drygalski.)

within the rock are able to exert a control over the location of waterways. We have already emphasized the fact that in high latitudes, where there is generally scant cover of vegetation and where frost work is the dominant weathering process, such control will be at a maximum and repeating relief patterns will in consequence be given a strong expression.

In western Greenland, where the fjords and valleys appear as definitely oriented right lines on the map, it has been shown that outlet glaciers

FIGURE 12.—*Rain-sculpturing controlled by Joints*

Coast of southern California. (After a photograph by Fairbanks)

from the inland ice actually clean out the talus deposits which collect in the bottom of clefts as a result of frost action upon their walls. These clefts, in consequence, are extremely narrow canyons which flare at both the top and bottom, as is shown in figure 11.[10] "They are," says von Drygalski, "too little developed for running water to have had a part in forming them."

[10] E. von Drygalski: Grönland-Expedition der Gesellschaft für Erdkunde zu Berlin 1891-1893, pp. 36-43, pl. 7.

In the semi-arid regions, where likewise the mat of vegetable material

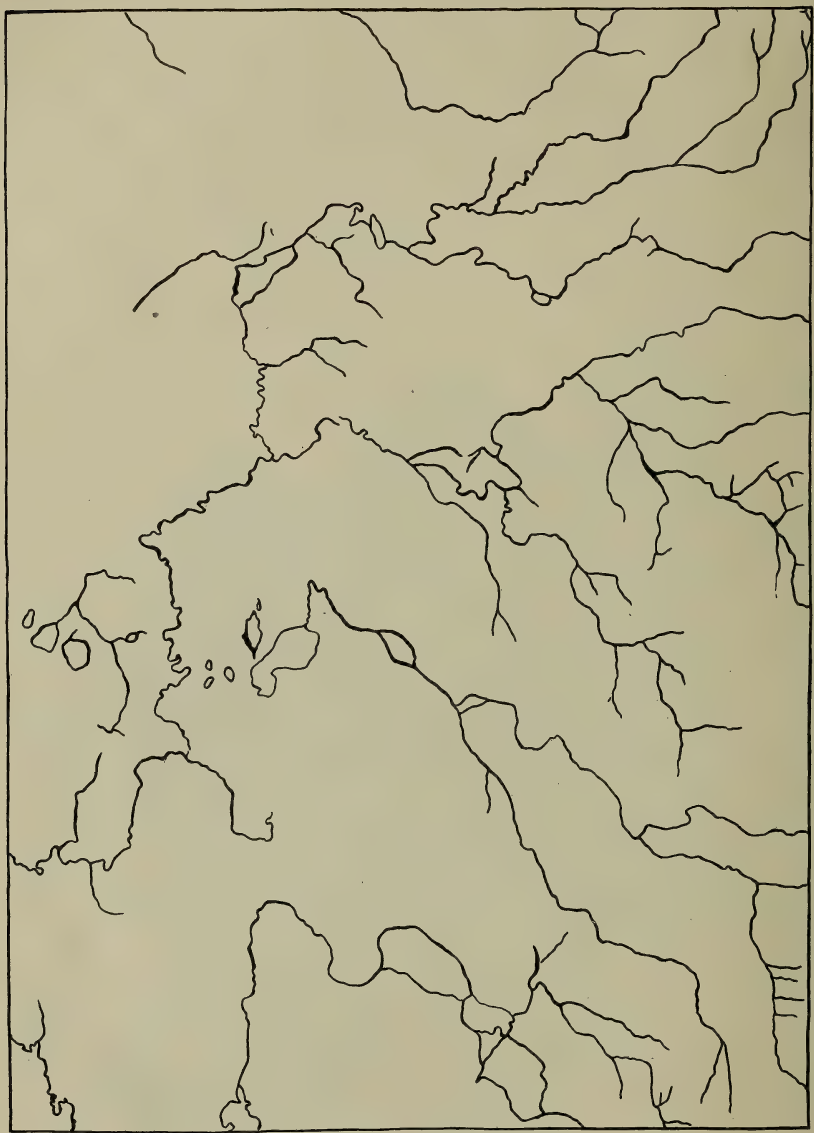

FIGURE 13.—*Drainage Map of the Redfield Quadrangle, South Dakota*

Showing control of drainage network by a fracture system. (After U. S. Geological Survey)

is lacking, and particularly on elevated plateaus where frost work is likely to be effective, a strong control of the drainage directions is to be looked

for. On the one hand, the dash of the rain makes a direct attack upon the uncovered fissure planes (see figure 12), and in the end produces the well known "bad land" topography. The stages in this process may be read in series of photographs taken in the "Bad Lands" area of South Dakota. Mushroom Park reveals on a small scale the effect of perfect rectangular jointing within a relatively thin layer. The atlas sheets representing a much larger area in South Dakota all reveal a drainage system controlled by joints (see figure 13).

The Pleistocene clays of Lake Bonneville, as was long ago shown by Gilbert,[11] have a well developed simple and oriented joint system. One

FIGURE 14.—*Batoka Gorge of the Zambesi River*

View is taken below the Victoria Falls. The river's course is directed on a system of fracture lines. The black line at bottom of gorge shows the stream width in the dry season, the dotted line the water line at flood. (After Lamplugh.)

of the diagnostic characteristics of the almost impalpable loess of the same recent age is that it stands on vertical joint walls of a fracture system identical with that found in the older and firmly consolidated rocks.[12] So far as the writer is aware, this interesting fracture system has never been vouchsafed an orientational or structural study. A remarkably perfect fracture system, on which erosion has brought out with great

[11] Gilbert: Monograph I, U. S. Geological Survey, pp. 211-213.
[12] See Chamberlin and Salisbury: Geology, vol. 3, pp. 405-412, figs. 523-524.

clearness the composite blocks of larger order, is represented by plate 12, figure 1. These structures are developed in deposits laid down behind an old irrigation dam in the Syrian desert.

Where in desert regions the action of frost becomes especially important, as on the Tian Shan Plateau, photographs show particularly well the controlling influence of the joint planes in the fashioning of the relief (see plate 10, figure 1). Here the larger sags in the horizon line are above spaced clefts, with smaller subequal intervals separating consecutive joints.

In the Kalihari of Africa are almost featureless plains which range through twenty degrees of longitude. In a part of this district the domi-

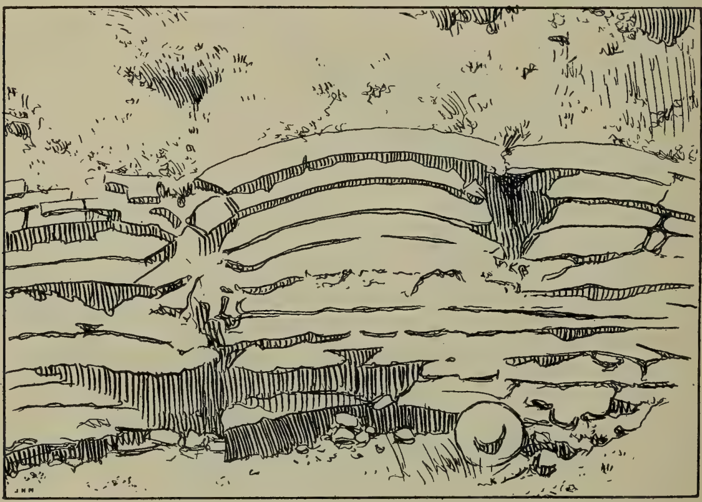

FIGURE 15.—*Sagging of Beds of thin, flaggy Limestone over Joints*
(After Gilbert, U. S. Geological Survey)

nant influence of a system of joints and faults in fixing the lines of drainage is well brought out by the Batoka gorge of the Zambesi River below the famous Victoria Falls. The gorge is here directed in largely rectangular zigzags, at the turnings of which are remarkable "elbows" where tributary streams enter the main gorge (see figure 14). Lamplugh has shown that the erosive work of the stream and its tendency to utilize the existing structure lines are much increased by the cloud-burst type of precipitation so characteristic of semi-arid regions.[13]

Within relatively humid regions the control of relief by fracture planes

[13] G. W. Lamplugh: The geology of the Zambesi basin around the Batoka gorge (Rhodesia). Quarterly Journal of the Geological Society, vol. 63, 1907, pp. 187-195, figs. 4-8.

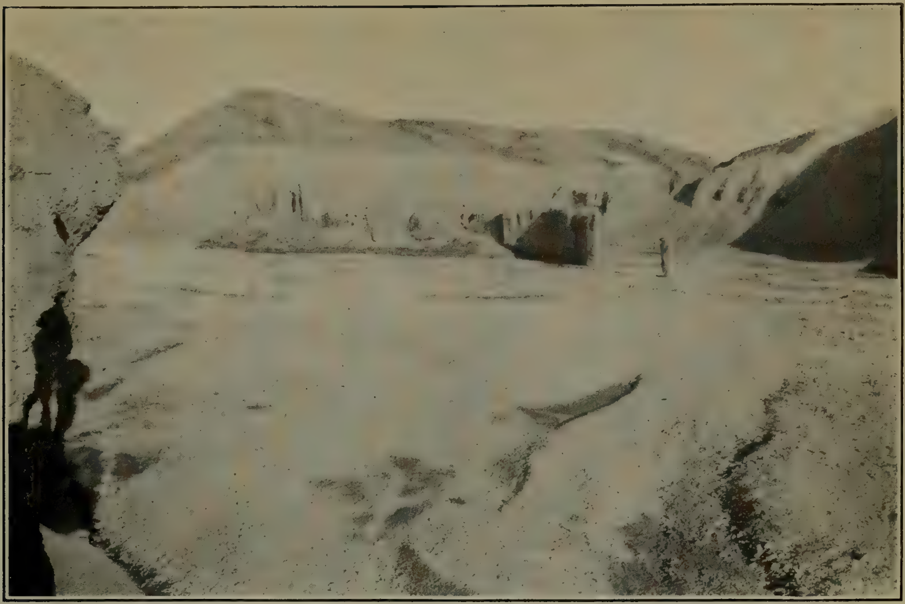

FIGURE 1.—ILLUSTRATION OF CONTROL BY A FRACTURE SYSTEM AT HIGH ALTITUDES WITHIN A DESERT REGION

A spaced joint system is betrayed in the rock wall of the middle distance, while a regular sagging of the horizon line above visible fracture planes is to be made out. The altitude is 12,000 feet upon the Tian Shan plateau. (Photograph by Ellsworth Huntington.)

FIGURE 2.—VIEW LOOKING DOWN THE SARANAC RIVER IN THE VICINITY OF CADYVILLE

The perfect joint structure within the Potsdam sandstone has brought about rectangular turnings in the river. (After a photograph by W J McGee, through courtesy of C. E. Peet.)

RELIEF FORMS CONTROLLED BY THE FRACTURE SYSTEM

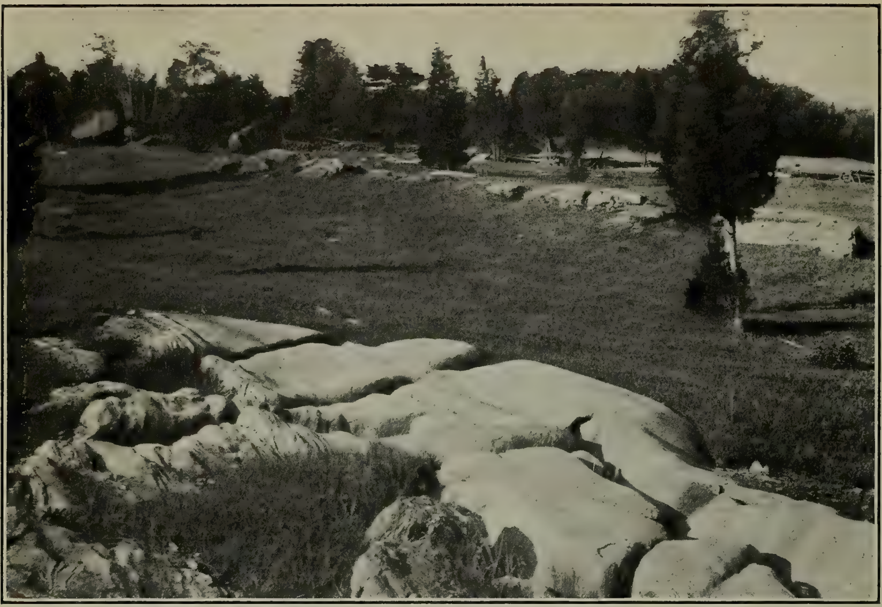

FIGURE 1.—JOINTS WIDENED AT THE SURFACE THROUGH SOLUTION BY DESCENDING METEORIC WATER

In white crystalline limestone at Sheffield, Massachusetts. (Hobbs, U. S. Geological Survey.)

FIGURE 2.—CONTROL OF DRAINAGE BY JOINT PLANES NEAR ITHACA, NEW YORK

(After a photograph by Tarr)

CONTROL OF DIRECTION OF WATERWAYS IN HUMID REGIONS OF MODERATE LATITUDES

within the rock basement is obviously less than it is where the surface is unprotected by vegetation, yet accurate maps must show in how far a direction control exists. That the influence of frost work will be lessened is certain, but other processes are also subject to control (see plate 11). Experience shows that areas underlain by limestone are especially responsive to directing influences during denudation because of the solvent property of the water which percolates through them on fracture planes. This is illustrated by plate 11, figure 1, which shows joint planes widened by solution within compact crystalline limestone. How the upper layers of a relatively flaggy type of limestone come to sag over joints, and thus start the course of waterways, is shown in figure 15.

FIGURE 16.—*Map of the Vicinity of the Moldefjord in western Norway*

Showing how one relief pattern (about the Langfjord) is merged in another (about the Eikesdalsviken)

A study of accurate hydrographic maps, as already stated, may be relied upon to show in how far fracture control is exercised in those districts of lower latitude where vegetable cover and other modes of weathering are the rule. Ignoring, then, for the moment the theoretical side of the problem, and attempting only to observe the evidences of systematic control of drainage in accordance with any repeating pattern, it may be said that many excellent observers have supplied striking examples of such control and from widely separated districts.

The best known examples are those given by Daubrée in his monumental work on experimental geology, in which regularly oriented net-

works in northwestern Europe are described and explained by joint control.[14] At about the same time Kjerulf[15] brought out identical facts for Norway. A less familiar example from the same early period, but from an American district, was described by Alexander Winchell, though the explanation which he offered (formation strike combined with glaciation) seems almost fantastic in view of the known facts.[16]

MERGING OF NETWORK PATTERNS

The cases which have been cited as examples of repeating relief patterns show how a simple diaper-like design is many times repeated within

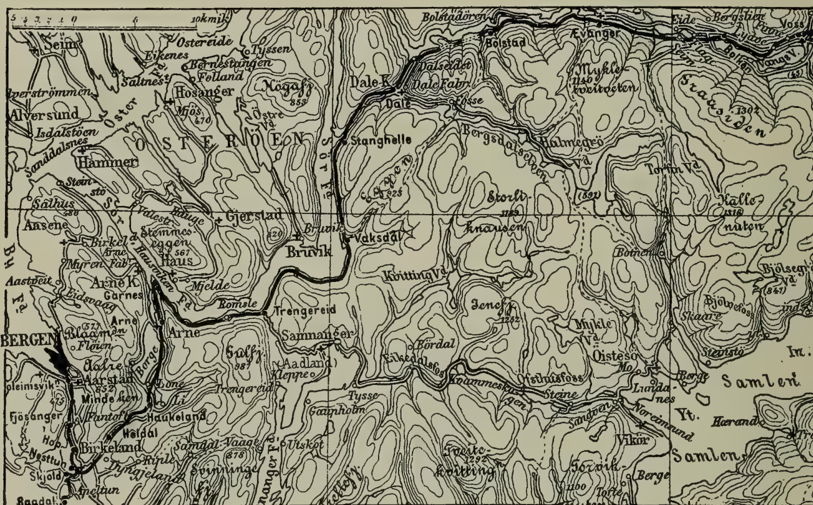

FIGURE 17.—*Map of the Vicinity of Bergen, Norway*

Showing the merging of different relief patterns

any given district. Such repetition does not, however, go on indefinitely. With rather remarkable abruptness such patterns disappear or give place to others of a slightly different character, but generally merely differently oriented. This may be illustrated by portions of the map of Norway. Thus the area about the Moldefjord reveals a regular rectangular pattern near the Fannefjord and Langfjord, which is not of identical orientation with that to the east of the Eresfjord and the Eikesdalsviken (see figure 16). Again, the vicinity of Bergen may be used to illustrate such an abrupt change of pattern in the relief. Here about the Osterfjord a

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[14] Daubrée: Géologie Expérimentale, Paris, 1879, pl. iii, figs. 1-2.

[15] Kjerulf: Loc. cit., pp. 328-334.

[16] A. Winchell: The diagonal system in the physical features of Michigan. American Journal of Science (3), vol. 6, 1873, pp. 36-40.

sharply rectangular pattern having subequal space intervals is in contrast with a more intricate pattern to the east of the upper Sörfjord (see figure 17). Such a merging of patterns is schematically represented in figure 18.

PATTERNS OBSCURED BY BEDPLANES AND FORMATION BOUNDARIES

It needs to be emphasized that the evidence of control of relief by fractures on the one hand or by folds on the other, will in general be expressed by the straightness or the curvature respectively of the stronger lines in the plan. This is well illustrated by a comparison of figures 1 and 2 (see pages 125 and 126). In the case of folds, it appears to be

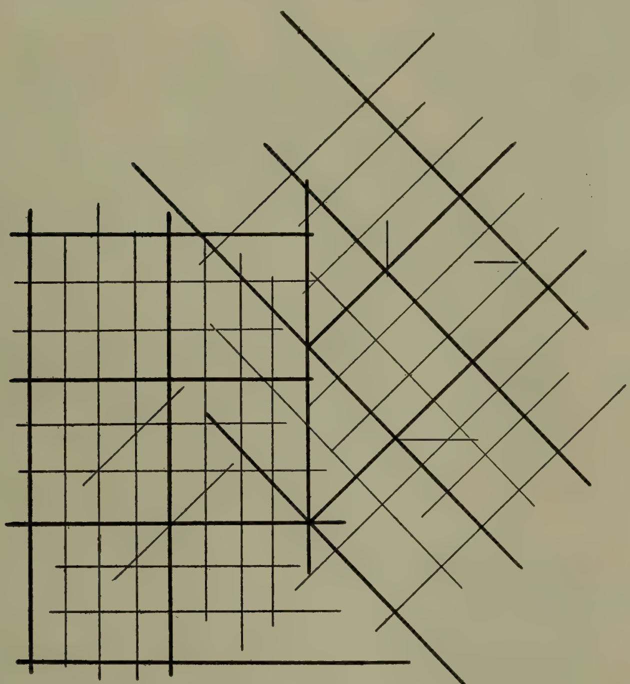

FIGURE 18.—*Schematic Representation of the merging of two Relief Patterns*

the strength or weakness of rock beds which are the determining factors, and a similar curvature but generally lesser regularity of lines will result from the presence of intrusive igneous rocks in other forms than dikes, which latter, being located upon fractures, exert their influence upon the relief in a similar manner. In proportion, then, as fold structures are prominent and fracture systems but little developed in any given district, repeating patterns will be obscure and often indistinguishable by the eye alone. Thus the effect of folding is added to that of erosion in

removing from sight significant structure lines in the relief. Where both fold and fracture structures are well developed in the same district, the

FIGURE 19.—*Fracture Relief Patterns locally obscured by Dominance of Fold Structures*

The largest island in the group betrays in its curving lines the influence of folds, while the smaller land masses to the southeast are cut into compartments on fracture lines. (From the Vaxholm sheet of the official topographic map of Sweden.)

one structure or the other may locally dominate the relief forms, as is brought out by figure 19.

In districts of only moderately accented relief, folds without pitching axes will be represented by straight and parallel elements in the relief,

since the curvature of folds *in the plan* is a direct measure of the plunging character of the crest or trough lines.

OBSCURE PATTERNS REVEALED IN STUDIES OF THE JOINT SYSTEM

Whenever the relief pattern due to control by a fracture system is too obscure to be directly read from the map, the evidence for partial control in the orientation of waterways may often be found by comparing the directions of master joints within the rocks of the district with the directions of the neighboring stream-courses. Studies of this character have been carried out, among others, by Harder,[17] Lind,[18] and the writer.[19]

The dividing Lines of Relief Patterns—Lineaments

THE VARIED EXPRESSION OF LINEAMENTS

We have seen that the repeating patterns of the relief, whether expressed in topographic or in hydrographic maps, are divided on lines which, for limited distances at least, are essentially rectilinear. These lines may be expressed in shores, fjords, valleys, escarpments, sags, or in

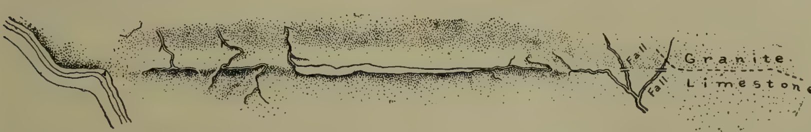

Figure 20.—*Schematic Diagram indicating the composite Expression of a Lineament*

the equally definite stream lines. Generally they are expressed in one portion in one way and in another portion by a different feature—they are essentially composite in their expression. Often where the drainage network alone does not clearly reveal the pattern or the dividing lines, a supplementary study of the topographic or geologic map may do so (see figure 20). Thus a waterway may be continued by a sag or trench not brought out in the hydrography, or by a line of waterfalls in transversely flowing streams, or, lastly, by a significant boundary between geological formations. However expressed, these approximately right lines in the

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[17] E. C. Harder: The joint system in the rocks of southwestern Wisconsin and its relation to the drainage network. Bulletin of the University of Wisconsin, Scientific Series, vol. 3, No. 5, 1906, pp. 207-246, pls. 1-10.

[18] J. G. Lind: Geologische Untersuchungen der Beziehungen zwischen Gesteinspalten, der Tektonik und dem hydrographischen Netz des Gebirges bei Heidelberg (mit einer karte). Verh. d. naturh. medicin. Vereins zu Heidelberg, N. F., vol. 11, 1910, pp. 7-45.

[19] W. H. Hobbs: Examples of joint controlled drainage from Wisconsin and New York. Journal of Geology, vol. 13, 1905, pp. 363-374.

plan of the earth's surface have been designated *lineaments*—significant lines in the earth's face.[20]

In part it is the composite expression of these lines and in part it is the impertinent intrusion on the geologists' attention of the culture overprinted on topographic maps which is responsible for a general failure to take note of these significant character lines in the relief. Further, it is to be emphasized that since the time of de Beaumont the attention of geologists has been so largely withdrawn from the plan of the earth and focused upon its buried and invisible structure that what may be called *orientational physiography* is yet in its infancy.

It can not be too strongly emphasized that the question of the existence of lineaments in the relief of any particular district is quite distinct from that of the process or processes by which the topography along the line in question may have been shaped. To illustrate, it has sometimes been urged that a certain markedly rectilinear trench on the surface can not have its origin in a fracture line of the crust for the reason that it has been shaped by stream erosion, by a mountain glacier, or by some other well recognized geological agent.[21] It is, however, the *control of direction, not the details of sculpture*, which is here of significance. To quote an early worker in this field:[22]

"Thus the great system of fractures which intersects the surface furnishes the primary lines for the aspect of the surface of Norway. The mysterious network of these lines is stamped in indelible characters; it may indeed remain a long time unnoticed, but if one has once seen it, it will never again escape his observation. Like a moss-grown inscription upon a slab of marble, it is there and to be deciphered. Here all embodied representations of plateaux, inclined planes, and erosion of every sort, have not succeeded in hiding the inscription and withdrawing it from observation; brush these once aside and the eye can again clearly discern the runic characters, and it thus depends only upon this that they all be correctly understood in the future."

RELATION TO JOINTS AND FAULTS

That lineaments are above rock fractures in the earth, their approximation to straight courses and their parallel arrangement testify. It does not seem necessary to assume that they are in all cases above lines of faulting, since drainage networks repeat in regular patterns where no

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[20] W. H. Hobbs: The lineaments of the Atlantic Border region. Bulletin of the Geological Society of America, vol. 15, 1904, pp. 483-506, pls. 45-47. Also Comptes Rendus Congrès Géogr. Inter., 1906, pp. 193-203.

[21] Such a line of argument was made prominent in the discussion of two papers dealing with the influence of structure planes in modifying the relief, which were read at the International Congress of Geologists at Stockholm in August, 1910.

[22] Kjerulf: Loc. cit., p. 334.

evidence of faulting is obtainable and where the absence of important planes of dislocation is to be assumed. Abnormally wide gaping of joints at regular intervals, as has been above described for Norwegian localities, may largely account for their regular space intervals.

Among the many examples of stream channels directed by joints may be cited the "dells" of the Wisconsin River, near Kilbourn City, Wisconsin;[23] the Saranac River, in New York, and the Abisko Canyon, in Swedish Lapland (see figure 21 and plate 13, figure 1).[24]

On the other hand, within many districts block faults are known to be present, composing a system which is in every way similar as regards arrangement and orientation to the oriented drainage network; as, for example, the Norwegian coast region or the middle Rhine country. Of Norway is is stated:[25]

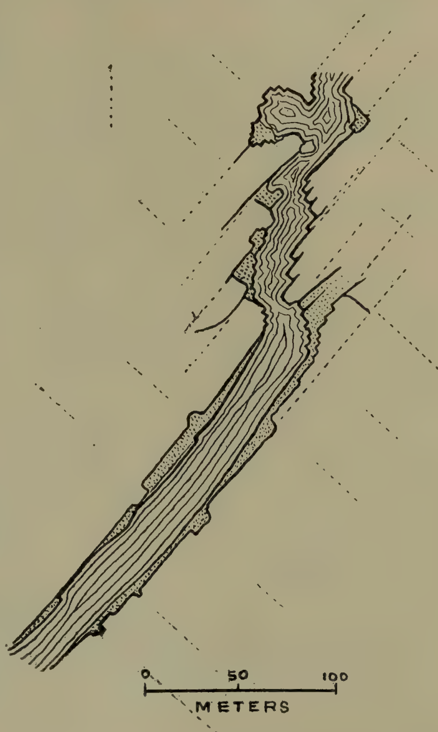

FIGURE 21.—*Map of the Abisko Canyon in northern Lapland*

The canyon is directed along the line of rectangular joints visible in the canyon walls. (From the map by Otto Sjögren, with indications of spacing added)

"The character of the surface near the coast may be expressed by the statement that it is broken up into steps, so that one rises from the first to the second and thence to the third step, encountering each time the same formation wherever the great step series is to be observed."

Again:[26]

"In the little strip of Paleozoic formations between Langesund and the Skiensthal we have before us, then, a section of country which is penetrated through and through by faults upon already formed joint planes. We have seen that the lines of the landscape are given by the principal joint systems.

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[23] C. R. Van Hise: The origin of the dells of the Wisconsin. Transactions of the Wisconsin Academy of Science, vol. 10, 1895, pp. 556-560.

[24] Otto Sjögren: Geografiska och Glacialgeologiska Studier vid Torneträsk. Sveriges Geologiska Undersökning, Arsbok 3, 1909, No. 2, pp. 34-45, figs. 15-16.

[25] Kjerulf: Loc. cit., p. 329.

[26] Brögger: Loc. cit., p. 400.

They have in part reduced the work of erosion; in part they have allowed numberless dislocations to form which offered new points of attack to the erosion." . . .

With little doubt the control of drainage lines exercised by gaping joints within the rocks, is much facilitated wherever dislocation has induced crushing upon any plane, or wherever the relief has been in any way modified through actual displacement at the surface.

Identity of many strong Lineaments with seismotectonic Lines

Character of seismotectonic lines

That lineaments are, in many cases at least, above the seats of recent fault movement is indicated in their general correspondence with known seismotectonic lines—the selective lines of heavy shock in connection with earthquakes.[27]

Seismotectonic lines are sometimes given a visible expression due to the derangements of underground water-flow during an earthquake. The

Figure 22.—*Sand cones aligned along a Fissure*

This fissure opened at Moraza, in Servia, during an earthquake which occurred on April 4, 1904. (After Michailovitch)

fractures over which they lie become at such times the channels for abnormally large water currents carrying sand or mud from deeper lying layers upward to the surface—they are much swollen, but temporary fissure springs. For the reason that the fractures are not uniformly gaping, but appear to be enlarged wherever two or more series intersect, there is a tendency for water-flow to be greatest at crossing points, which thus become the loci of earthquake fountains and leave behind residual craterlets, sand cones, or mud volcanoes (see, for example, figure 22).

Whenever the mud cones are so large as to make prominent features in

[27] W. H. Hobbs: On some principles of seismic geology. Gerland's Beiträge zur Geophysik, vol. 8, 1907, pp. 223-227. Earthquakes, an introduction to seismic geology. New York, 1907, pp. 96-119. German translation of same. Leipsic, 1910, pp. 76-93. F. de Montessus de Ballore: La Science Séismologique. Paris, 1907, p. 449, fig. 164.

the relief, they are spoken of as mud volcanoes, and in some cases these rise as islands in the sea or other bodies of water, thus revealing facts of structure not otherwise obtainable. An island of this nature formed near the head of the Bay of Bengal, in December, 1906.[28] Under specially favorable circumstances the repeating pattern of a fracture system may be brought out by the arrangement of the mud volcanoes. In the southern half of the Caspian Sea, islands formed in this manner and hills of like formation upon the shore reveal in great perfection the outlines of a structure pattern, as was long ago shown by Abich (see figure 23).[29] Here the northeasterly series of lineaments is intersected by a northwesterly series, which not being perpendicular to the first produces a diamond-shaped pattern. There is, however, a suggestion that a per-

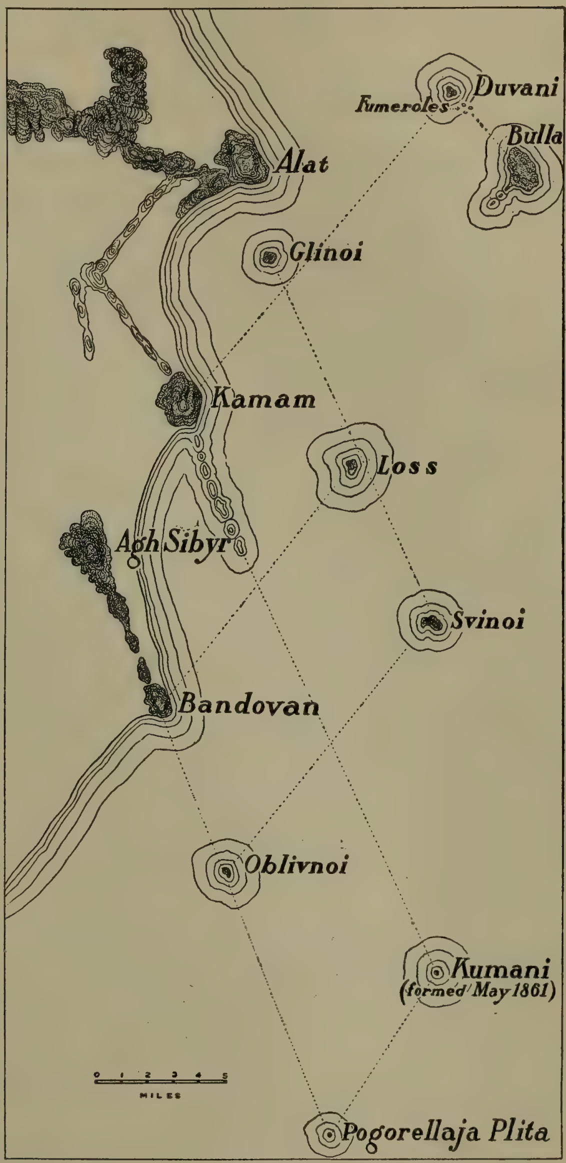

FIGURE 23.—*Fracture Pattern*

Revealed on the bottom and on the shore of the Caspian Sea by the arrangement of mud cones and mud islands (stippled) at the intersections of lineaments. (After Abich.)

[28] E. J. Headlam: A new island in the Bay of Bengal. Geographical Journal, vol. 29, 1907, pp. 430-436, figs. 1-6.

[29] H. Abich: Eine im Caspischen Meere erschienene Insel nebst Beiträgen zur Kenntniss der Schlammvulkane der Caspischen Region. Mém. Acad. Imp. Sci. de St. Petersburg, ser. vii, vol. 6, No. 5, 1863, pp. 1-151, pls. 1-3.

pendicular northwesterly series, even if subordinate, is none the less present; as, for example, in the Duvani-Bulla line to the northeast on the map.

THE MESH-LIKE ARRANGEMENT OF VOLCANIC VENTS

The arrangement of volcanic cones is generally ordered in a pattern of lines which is often known to be, and at other times is believed to represent, fissure lines within the crust. This was long ago pointed out by Darwin, and has found confirmation in the writings of many later vulcanologists, notably Thoroddsen and Verbeek. The meshlike arrangement of volcanoes, and its origin in a fracture system, has on the basis of recent literature been more fully discussed by the writer in another place.[30]

The Correlation of Fracture Fields

CONTROLLED FRACTURE FIELDS OF NORTH AMERICA

Winchell's "diagonal system" of Michigan had reference to the topographical and hydrographical features of the State of Michigan and neighboring areas in Ohio, Wisconsin, and Ontario. Here the drainage lines are very generally ordered in northeast-southwest and northwest-southeast directions, as well as on the somewhat less important meridional and trans-meridional directions. In this respect, then, the province may be looked upon as having common elements of structure, whatever differences of rock composition or of geological history may be represented by its component and widely separated parts. Such sections of the earth's surface, which are chosen more or less arbitrarily on grounds of convenience, may be referred to as fracture fields.

Any one who will take the trouble to examine the later maps of the country surrounding the upper Laurentian lakes may easily convince himself that the directions claimed by Winchell to control have exercised a dominating influence on the hydrography. In figure 24 is reproduced an area taken almost at random from the most recent hydrographic map of northern Michigan, and in figure 25 the drainage network near Lake Temiscaming, in Ontario.[31] Within this district the cobalt veins

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[30] Proceedings of the American Philosophical Society, vol. 48, 1909, pp. 17-26.

[31] W. G. Miller: The cobalt-nickel arsenides and silver deposits of Temiskaming. Report of the Bureau of Mines, vol. 14, pt. ii, 1905, pp. 28-31; ibid. (3d ed.), vol. 16, pt. ii, pp. 36-38, fig. 15.

W. H. Hobbs: Transactions of the Wisconsin Academy of Science, vol. 15, pp. 15-29 (issued August, 1905).

L. V. Pirsson: Crustal warping in the Temagami-Temiskaming district, Ontario. American Journal of Science, vol. 30, 1910, pp. 25-32.

have been found to run parallel to the northeast-southwest lines of the drainage network, and by utilizing the information derived from this source concerning spacing, Doctor Miller has been able successfully to follow out the continuations of interrupted ore bodies. In both these examples it should be noted not only that the drainage network betrays a definite orientation of waterways along either the cardinal or their bisecting directions, but that there is a subequal spacing of the streams in units of different orders. Essentially the same orientation and spacing is betrayed by one of Harder's published maps from southwestern Wisconsin.[32] Buckley has shown that the prevailing joints in practically all quarries of Wisconsin indicate a dominance of the four directions toward the cardinal points and along their bisecting lines. He says:[33]

FIGURE 24.—*Drainage Map of the Area about Rockland, in northern Michigan*

Showing an arrangement of streams on north-south, east-west, and northwest-southeast lines. The divisions in the margin represent miles. (Nellist's map)

"As will be seen by the accompanying map, the joints of the sedimentary rocks strike in four main directions. The prevailing general direction of the joints is northeast and southwest. The other directions are northwest and southeast, east and west, and north and south."

On the north shore of Lake Superior the vertical dikes of Keweenawan rock are in two series, one of wide dikes trending northeast to southwest, the other of narrow dikes about northwest to southeast.[34] Like directions

[32] Harder: The Richland Center District. Loc. cit., pl. 3.

[33] E. R. Buckley: On the building and ornamental stones of Wisconsin. Bulletin of the Wisconsin Geological and Natural History Survey, No. 4, 1898, p. 459, pl. 49.

[34] A. C. Lawson: Twentieth Annual Report of the Geological and Natural History Survey of Minnesota, 1893, p. 193.

hold for the French River[35] (see figure 26) and Trent River[36] districts in

FIGURE 25.—*Drainage Map of a Part of the District of Nipissing*

Showing patterned arrangement on northwest-southeast and northeast-southwest lines. (Ontario, 1905)

[35] Robert Bell: Report on the geology of the French River district, Ontario. Annual Report of the Geological Survey of Canada, new series, vol. 9, 1896, pp. 120-121. Also Bulletin of the Geological Society of America, vol. 5, 1894, pp. 357-366, pls. 15-16.

[36] A. W. G. Wilson: Trent River system and Saint Lawrence outlet. Bulletin of the Geological Society of America, vol. 15, pp. 211-242, pls. 5-10, and drainage maps.

Ontario to the eastward of Lake Huron, for Iowa,[37] and for portions of Arkansas.[38]

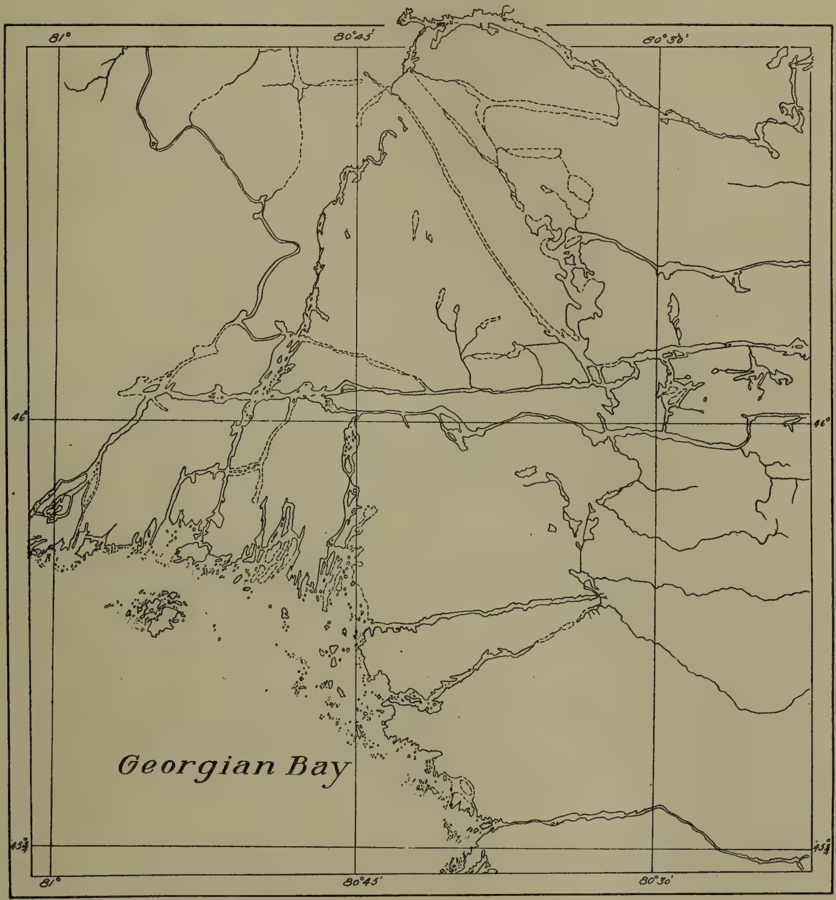

FIGURE 26.—*Map showing oriented Drainage of the French River District, Ontario*

That the same directions also control in many districts scattered throughout the United States is indicated by a considerable body of evidence presented by the writer in 1905.[39]

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[37] W J McGee: Note on jointed structure. American Journal of Science, 3d ser., vol. 25, 1883, pp. 152-155. Also Transactions of the Wisconsin Academy of Science, vol. 15, p. 21.

[38] J. F. Newsom and J. C. Branner: The Red River and Clinton monoclines. American Geologist, vol. 20, 1899, pp. 1-13.

[39] The correlation of fracture systems and the evidences for planetary dislocations within the earth's crust. Transactions of the Wisconsin Academy of Sciences, vol. 15, 1905, pp. 15-29.

Some further districts will be mentioned within which the evidence for a patterned system of fractures is specially clear. A study of the joint system of the Long Lake quadrangle in the Adirondacks of New York State has revealed two rectangular series bisected by a second and similar double series. The one set corresponds to the meridional and trans-meridional directions, the other to directions bisecting the angles of the first.[40] From the Elizabethtown quadrangle of this district was taken in 1904 the author's type example of checkerboard topography, which showed a rectangular pattern orientated on northwest-southeast and northeast-southwest lineaments.[41] This map is reproduced in plate 9. Kemp and Ruedemann, in a very recent paper, say of the drainage of this and neighboring quadrangles :[42]

"At the headwaters of both the Schroon and the Boquet are some extremely interesting features which also extend into the neighboring quadrangles. The marked northeast and northwest structural lines have caused even the little brooks to follow them. We may start at the source of some little tributary . . . and follow the stream around three sides of a rectangle, each turn being a sharp angular one.

. . . .

"The trellised drainage is believed by the writer to be due to a pronounced system of block faulting which has broken up the country into these marked divisions, and which by sheeting the rock along the lines of movement has produced the vulnerable portion searched out by the moving water.

. . . .

"Besides the northeast and southwest (northwest? W. H. H.) systems of drainage just described there is in this quadrangle and still more in neighboring ones evidence of north and south valleys, and of east and west ones which are older."

From the vicinity of Cayuga Lake, in western New York, have been taken the remarkably perfect examples of joint systems with rectangular master sets which are now classical, because published in the works of Dana and Hall. Here the two dominating series trend near the meridian and at right angles to it.[43]

The dominance of three out of the four prevalent fracture directions—northeast-southwest, northwest-southeast, and north-south—as major lineaments for the entire Atlantic border region of the United States was

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[40] H. P. Cushing: Geology of Long Lake quadrangle. New York State Museum, Bulletin 115 (geology 14), 1907, pp. 493-495.

[41] Bulletin of the Geological Society of America, vol. 15, 1905, pl. 47.

[42] J. F. Kemp and R. Ruedemann: Geology of the Elizabethtown and Port Henry quadrangles. New York State Museum, Bulletin 138, 1910, pp. 16-17.

[43] H. S. Williams, R. S. Tarr, and E. M. Kindle: Geologic atlas of the United States, Watkins Glen-Catatonk folio (field edition). Washington, 1909, p. 109.

brought out in 1904.[44] A subequal spacing of these lineaments was also indicated, the large interval of the northeast-southwest series being 125 miles, that of the northwest-southeast series about 75 miles, and that of the north-south series about 40 miles. Patterned drainage from western Connecticut, in accordance with these directions, is brought out in figure 27.

Similar examples of patterned and oriented fracture fields have been found also in western sections of the country. Of the basin ranges of Nevada and California, Spurr says:[45]

> "The chief faults belong to the north and south and east and west systems. There are also diagonal ones running northeast and southwest, and in each of the systems they may have a very great displacement."

The clays of lakes Bonneville[46] and Lahontan[47] are intersected by an elaborate joint system of essentially the same orientation.

In the Yellowstone National Park, Iddings has described a network of faults which have produced a "fracture valley system" in which the dominant directions are northeast - southwest, northwest - southeast, north-south, and east-west.[48] From the Sierra Nevadas, Lawson has published a map which discloses a striking orientation of faults and drainage lines in harmony with the quadruple set of lineaments found in the other districts (see figure 28).[49]

FIGURE 27.—*Patterned Drainage of the Shepang Valley, Connecticut.*

(Hobbs, U. S. Geological Survey)

[44] W. H. Hobbs: Lineaments of the Atlantic Border region. Bulletin of the Geological Society of America, vol. 15, pp. 483-506, pls. 45-47.

[45] J. E. Spurr: Origin and structure of the Basin ranges. Bulletin of the Geological Society of America, vol. 12, 1901, p. 241.

[46] G. K. Gilbert: Post-glacial joints. American Journal of Science (3), vol. 23, 1882, pp. 25-27. Also Monograph I, U. S. Geological Survey, 1890, pp. 211-213.

[47] I. C. Russell: Geological history of Lake Lahontan. Monograph XI, U. S. Geological Survey, 1885, pp. 162-163.

[48] J. P. Iddings: A fracture valley system. Journal of Geology, vol. 12, 1904, pp. 94-105, plate.

[49] A. C. Lawson: The geomorphogeny of the Tehachapi Valley system. Bulletin of the Department of Geology of the University of California, vol. 4, No. 19, pp. 431-462, pl. 42.

In the Bullfrog district of Nevada nearly one hundred faults of steep hade have been recognized which fall mainly within two series, the one nearly north and south, and the other striking north 30° to 50° east, with a number of faults in other directions.[50] Matthes[51] reports from the Yosemite Valley of California that the dominating directions of vertical joints strike north 50 degrees east, north 30 to 40 degrees west, east-west, and north-south; the most prominent series being the northeast-southwest one. In addition to these vertical series, there are two inclined series, one dipping 30 to 40 degrees west and the other about 60 degrees east.

FIGURE 28.—*Map of the Tehachapi Valley*

Showing the known faults, formation boundaries, and drainage lines. Full right lines are faults and dotted lines formation boundaries. (After Lawson's map)

It would appear, also, from statements by Hobson and Hill, that the same directions which control the fracture patterns within the United States have a dominating influence in Mexico. Says Hobson:[52]

"There are two predominant directions of faults, fractures, and folds in Mexico; firstly, from northwest to southeast, and, secondly, from northeast to southwest; the latter is less constant than the former. A third less frequent direction is east and west. . . . The mineral veins, which owe their origin to the volcanic rocks, exhibit very constantly a parallelism to the lines of relief."

[50] Ransome, Emmons (W. H.), and Garry: Geology and ore deposits of the Bullfrog district, Nevada. Bulletin 407, U. S. Geological Survey, 1910, pp. 68-69.

[51] Personal communication.

[52] B. Hobson: The volcanoes of Mexico. Scottish Geographical Magazine, vol. 23, 1907, pp. 25-27.

Of like tenor are the following statements by Hill:[53]

"In this mountain two distinct systems of faulting are discernible. The first system may be known as the north-south and northeast system, the other as the northwest fault system. The north 80 degrees west faults are related to the northwest system in age.

. . . .

"Many of the north 40 degrees west faults appear in parallel belts across the mountain range and nearly all the mineral outcrops seem to be closely associated with them.

. . . .

"As the writer has previously shown, nearly all of the great ore localities of Mexico are associated with faults in this north 40 degrees west direction. These faults are all of late geological origin, and probably the movements of the earth which made them are still going on, as testified by hot springs in the vicinity."

DISORDERLY FRACTURE FIELDS

It should not be inferred that the above described structural directions are supposed to be the only ones which have been found within the areas described. Detailed study of special districts has brought out the fact that there are far more complex fracture systems on vertical planes, arranged for the most part in parallel and intersecting series, as, for example, the Pomperaug Valley system of Connecticut (see figure 29).[54] The river system of the larger area of the State of Connecticut brings into prominence a portion of these fracture systems, as well as some additional ones.[55] Wherever such definitely oriented fracture series are to be made out, the control would appear to be largely exercised by disjunctive planes which approach the vertical.

Many fracture fields have, however, been studied in detail and found to reveal a complex of fractures so disorderly as to have defied arrangement within any regulated system. In the opinion of the writer, such districts may be explained by the superimposition upon a simpler system of later fractures due, presumably, to special and local conditions. Thus in figure 30 has been represented in a schematic way what is believed to be the fracture complex of central North America. In districts which may be either contiguous or widely separated, fracture patterns representing various combinations of the elements of a common type pattern have been made out, whereas in many intervening districts more disorderly

[53] Robert T. Hill: Geology of the Sierra Almoloya, with notes on the tectonic history of the Mexican plateau. Science, new series, vol. 25, May 3, 1907, pp. 710-712.

[54] The Newark system of the Pomperaug Valley, Connecticut. Twenty-first Annual Report of the U. S. Geological Survey, pt. iii, pp. 1-162, pls. 1-17, figs. 1-59.

[55] W. H. Hobbs: The river system of Connecticut. Journal of Geology, vol. 9, 1901, pp. 469-485, pl. 1.

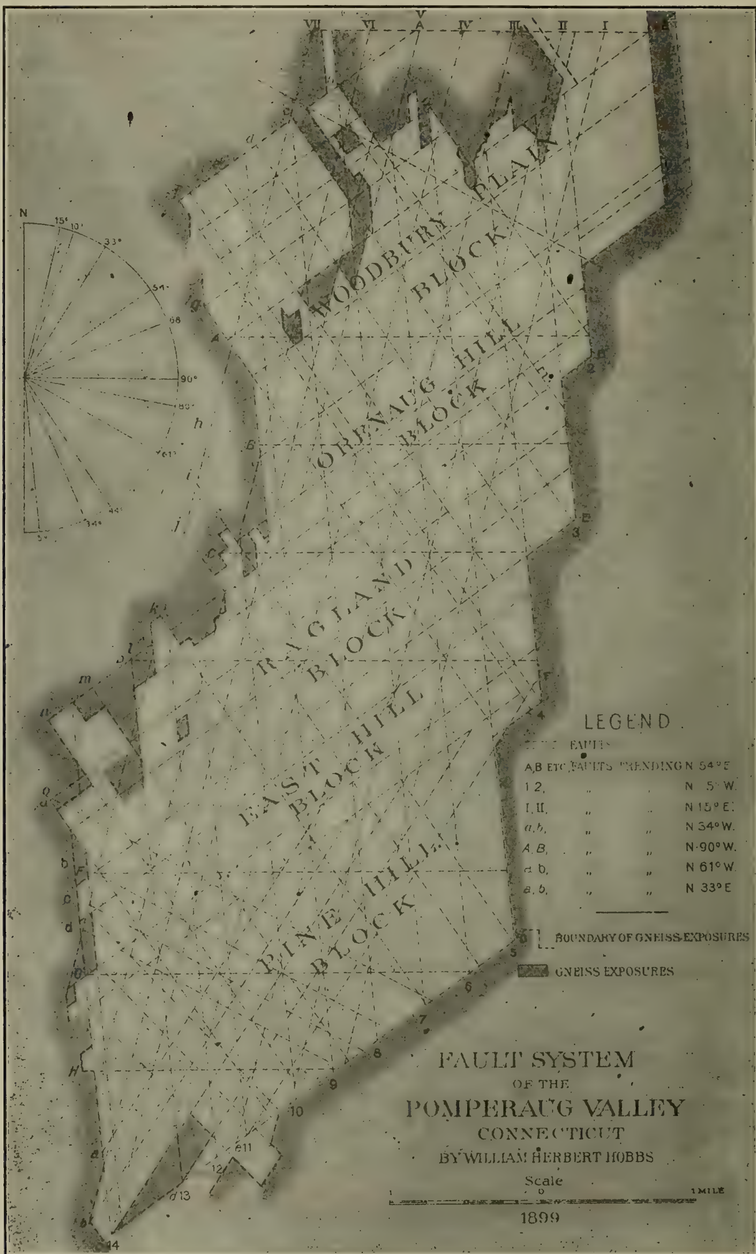

FIGURE 29.—*Outline Map of the Fracture System of the Pomperaug Valley Connecticut*

(Hobbs, U. S. Geological Survey, 1899)

fields have been encountered for which no law of arrangement has been discovered (figure 30, *a*, *a*, *a*). In general, it would appear to be true that in the more disorderly fracture fields the disjunctive planes of inclined hade are relatively more numerous.

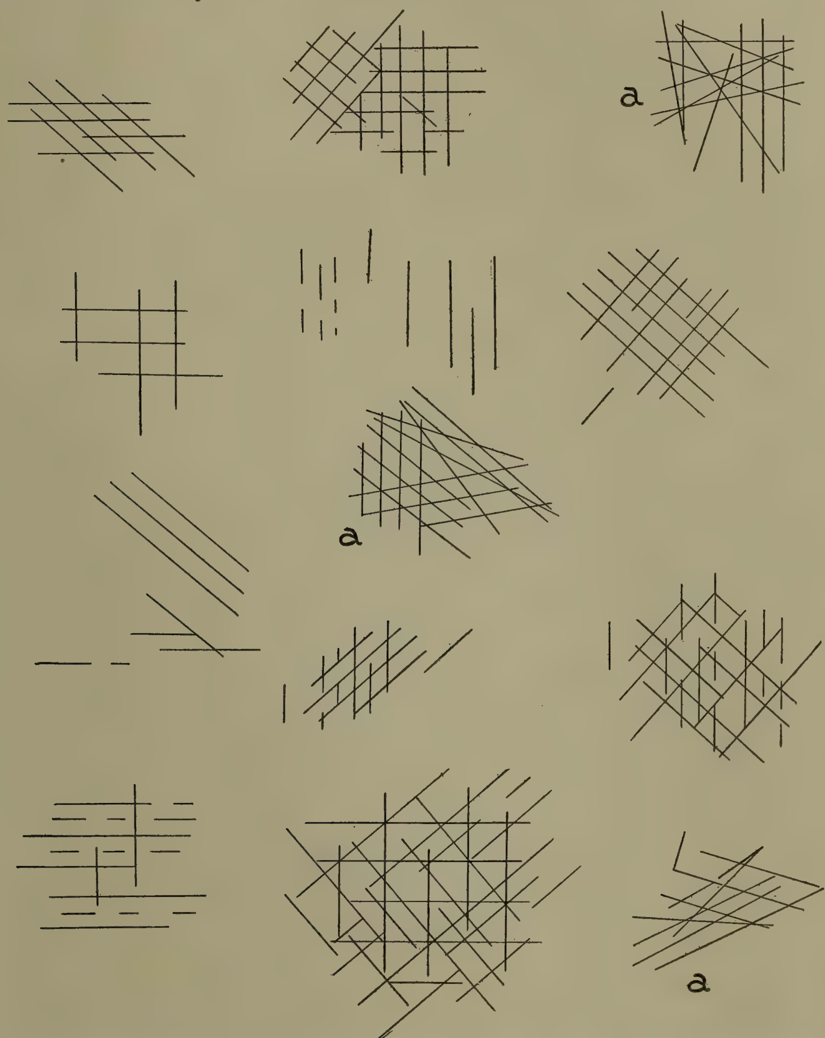

FIGURE 30.—*Schematic Representation of the Relations of the disorderly to the regularly patterned Fracture Fields of Central North America*

The practically uniform pattern and the like orientation within each of the orderly fracture fields, point clearly to a community of origin in stress conditions throughout an area of continental dimensions. It may

be that when we have advanced farther in our studies of fracture fields the more difficult fracture complexes may be deciphered, but for the present it is necessary to confine our attention to those within which some sort of orderly arrangement can be made out. *The significant fact is that wherever a relatively simple and orderly system has been discovered, the dominant structural and relief directions represent one or more of the elements within the quadruple set which has been above described.*

EUROPEAN FRACTURE FIELDS WHICH EXHIBIT CONTROL

As in North America, so also in Europe, the existence of districts of complex fracture structures has quite generally withdrawn the attention of geologists from the many districts which, as regards both their structural and their relief characteristics, are relatively simple. The writer has now for a number of years collected and compared the observations made in such districts, with the result of showing that the same quadruple set of dominant lineaments is common to Europe and North America alike. The data on which this conclusion has been based must be more fully presented in another place, but mention of a few districts will suggest the nature of the evidence assembled. That the above described quadruple set applies for Norway is clear from the studies made by Kjerulf more than a quarter of a century ago (see figure 7, page 132).[56] In southern Norway, Brögger's more detailed studies have shown the predominant influence of two of the four fracture series in the system—the meridional and trans-meridional—with the northeast to southwest series playing in addition a subordinate rôle:[57]

FIGURE 31.—*Oriented Drainage Network of the Vicinity of Charny, in France*

(After Daubrée)

"The dislocations—they are here movements along joints—have in fact cut the land through and through, and not alone in one system of lines, but, first, chiefly in two principal directions and then further on other less prominent directions. . . .

[56] Kjerulf: Loc. cit.

[57] W. C. Brögger: Spaltenverwerfungen in der Gegend Langesund-Skien, Nyt Magazin for Naturvidernskaberne, vol. 28, 1884, pp. 384-401-402.

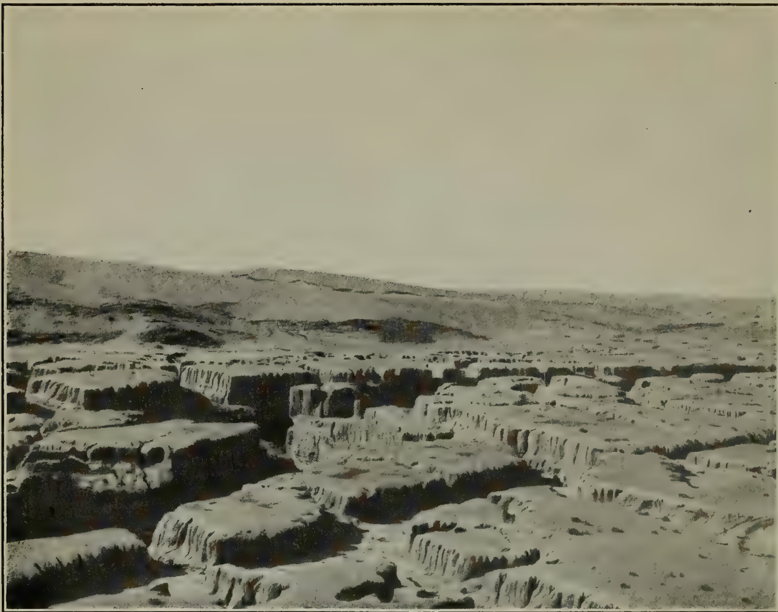

FIGURE 1.—A COMPOSITE RECTANGULAR RELIEF PATTERN

This composite repeating pattern of joints is made strikingly apparent through subsequent erosion of deposits back of an old irrigation dam at El Beida, in the Syrian Desert. (After a photograph by Ellsworth Huntington.)

FIGURE 2.—RECTANGULAR BUTTRESSING OF A WALL OF QUADER SANDSTONE DUE TO THE PERFECT FRACTURE SYSTEM

Valley of the Elbe, in Saxon Switzerland

"If here it be brought into consideration how closely the rocks are intersected by *quite small* dislocations, it follows in fact that a section of country cut up in this manner is built up as though out of separate squared stones."

From the southern shore of the Baltic a study of the fault system has shown the dominance of the northwest-southeast and northeast-southwest directions, corresponding, as we shall see, to the arrangement farther to the westward:[58]

"If from this description we derive a general view, we see that the entire northern portion of Hiddensoe, the Dornbusch, is intersected network fashion by fissures. These fractures allow us to make out two principal directions according to which they take their course. These are, in general, the direction northeast-southwest on the one hand and northwest-southeast on the other. Along these clefts we see the Pleistocene formation fall in in blocks."

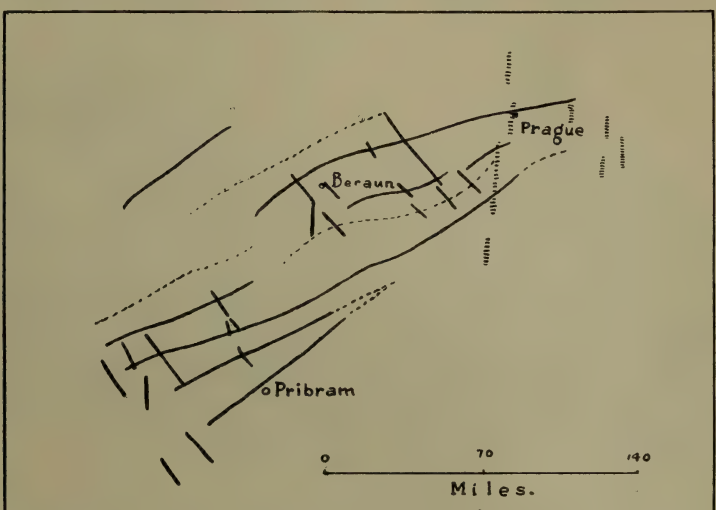

FIGURE 32.—*Fault System in the Silurian Basin of Central Bohemia*

The full and dotted lines are faults and the shaded lines porphyry dikes. (After J. Krejci and K. Feistmantel)

The maps published by Daubrée in his classical work illustrating the control of waterways by joints, and taken more especially from districts in northern and central France, bring out the same diagonal directions and the intermediate cardinal ones (see figure 31).[59]

Again, the scenically famous Saxon Switzerland may be cited, where the "Quader" (squared stone) sandstone is so perfectly blocked out by joints that it stands up in high mural faces with projecting squared but-

[58] A. Günther: Die Dislokationen auf Hiddensoe, Friedländer. Berlin, p. 58.
[59] Daubrée: Loc. cit., pp. 332-375, pls. 3-6.

tresses (see plate 12, figure 2). As Beck has shown,[60] these master joints are throughout the district ordered in two main perpendicular series, which are directed the one north-northeast and the other west-northwest, and that these have determined the directions of all the drainage lines. In addition, there is a faintly indicated east-west jointing, which, however, is not vertical, but dips northward at angles varying from 45 to 75 degrees. The writer has himself confirmed the correctness of these observations in parts of the district in question.

Another province of special significance in its relation to the fracture map of Europe is in southwest Germany about the middle Rhine, of which a fault map on large scale has recently been issued.[61] Here the faults are oriented in two dominant series, which determine the major features of

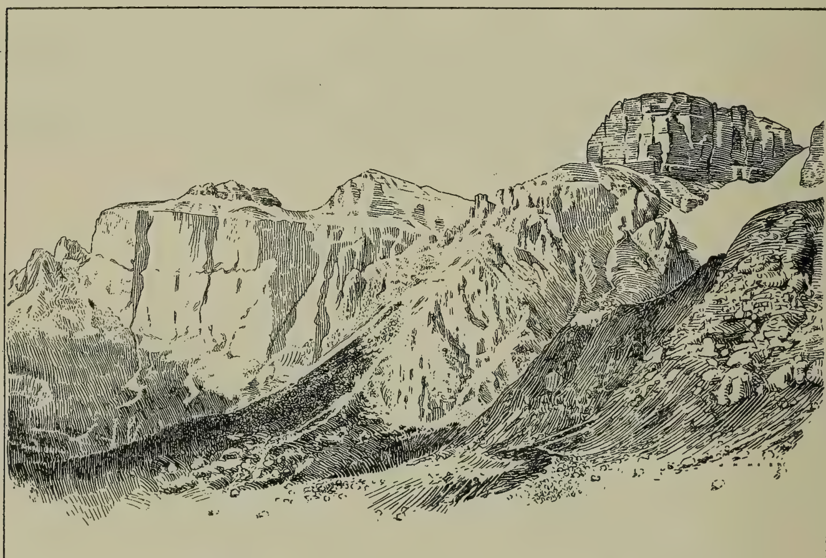

FIGURE 33.—*View of the Pordoi-Gebirge (Sella group) in the Dolomites*

Showing on the left unfaulted dolomite blocks of large size which are separated regularly by conspicuous joints, while in the higher block near the right of the picture may be easily recognized the smaller joint blocks in the Dachsteinkalk, which make up the larger unit. (After Mojsisovics.)

the relief, and are directed northwest-southeast and northeast-southwest, with some indication of the subordinate intermediate series.

Across the international boundary in central Bohemia the fault system

[60] R. Beck: Geologischer Wegweiser durch das Dresdner Elbthalgebiet zwischen Meissen und Tetschen. Berlin, 1897, pp. 99, 137-140, map.

[61] C. Regelmann: Tektonische Karte (Schollenkarte) Südwestdeutschlands, Herausgegeben vom Oberrheinischen Geologischen Verein, sheets 1-4 (Strassburg, Stuttgart, Metz, and Frankfurt). Justus Perthes, Gotha, 1898.

of the Silurian Basin is composed of two series which have the diagonal directions, with numerous porphyry dikes which are aligned along the meridian (see figure 32).[62]

Further south, on the borders of Austria and Italy, are the "Dolomites," well known to tourists for their remarkable scenery, the mountains appearing in squared towers, of which "Die Drei Zinnen" form a good example. As long ago shown by Mojsisovics,[63] the province is intersected by a complex of faults.[64] That in addition a finely developed joint system is present even where no faulting is to be observed, and that the individual joints are grouped into blocks of larger orders, is brought out in many photographs of the mountains—as, for example, in figure 33. Here we find, moreover, that the drainage system is definitely oriented on meridional and on diagonal lineaments (see figure 34). Speaking of the larger area of the Alps and the Tyrol, Salomon says:[65]

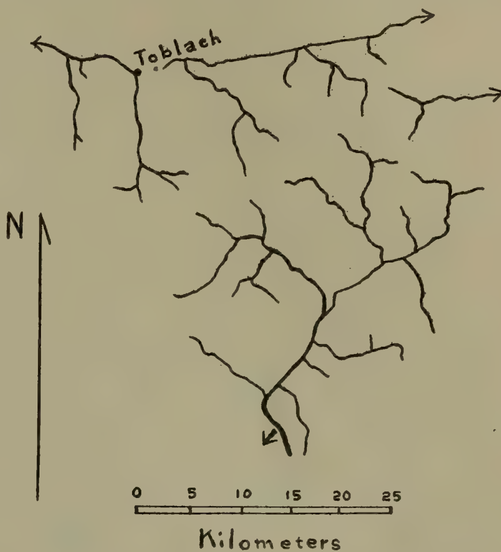

FIGURE 34.—*Drainage Network of the Dolomites*

Showing the dominance of meridional and diagonal lineaments

"Wherever a hydrographic system is investigated in relation to its connection with the mountain structure, it will always be shown that if not lines of displacement then, indeed, rock fissures are present which determine the direction of the running water."

For districts in the southern Alps, Futterer has shown the predominance of faults in the north-south, east-west, and northeast-southwest direc-

[62] J. Krejci und K. Feistmantel: Orographisch-geotektonische Uebersicht des silurischen Gebietes in Mittleren Böhmen. Archiv f. d. naturw. Landesdurchf. v. Böhmen, vol. 5, No. 5, 1885.

[63] Edmund Mojsisovics von Mojsvár: Die Dolomit-Riffe von Südtirol und Venetien. Beiträge zur Bildungsgeschichte der Alpen. Vienna, 1879, pp. xiv and 552, many plates and figures.

[64] Mojsisovics: Loc. cit., pp. 515-516.

[65] Wilhelm Salomon: Die Adamellogruppe, etc. Teil I, Abh. d. k. k. geol. Reichsanst., vol. 21, 1908, pp. 1-26.

tions.[66] To the eastward of the dolomites the drainage betrays strikingly the control by fractures which take especially the diagonal and the meridional directions, as is true of the dolomites themselves (see figure 35).[67]

THE AFRICAN FRACTURE SYSTEM

Passarge in his great work *Die Kalihari*[68] has shown how "folds, faults, and joints, with and without the pouring forth of eruptive rocks, follow in many cases definite directions, which repeat themselves many times, and hence deserve special names." These are: (1) The Lombobo direction (north-south), (2) the Cape direction (north 90 to 110 degrees east), (3) the Kaffraria direction (north 40 to 60 degrees east), and (4) the Damara direction (north 35 degrees west). There are represented, therefore, two rectangular conjugate sets so oriented as nearly to bisect each other, as has been shown above to be the case for North America and Europe.

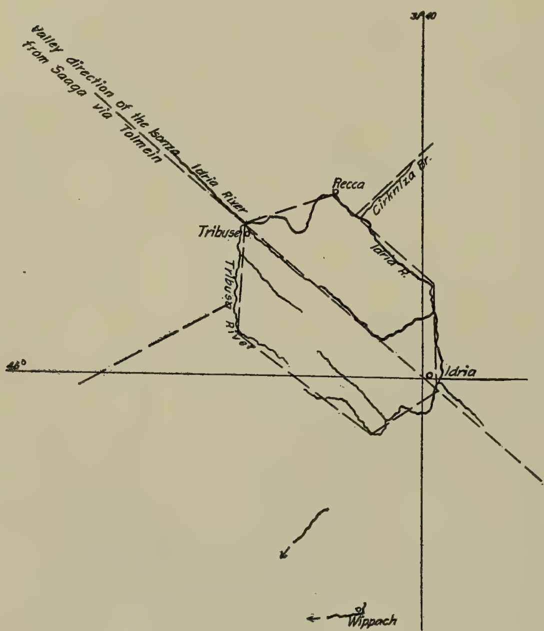

FIGURE 35.—*Oriented Drainage of the Idrea River*

Showing the dominance of the diagonal and meridional directions. (After Stur)

In a valuable compilation and correlation of the voluminous but much scattered scientific literature relating to the African continent, Simmer[69] also has shown that the feature lines are very largely conditioned by frac-

[66] Karl Futterer: Durchbruchsthäler in den Süd-Alpen. Zeitsch. d. Ges. fur Erdkunde zu Berlin, vol. 30, 1895, pp. 1-94, pls. 1-4.

[67] Diomys Stur: II, Das Izonzothal von Flitsch abwärts bis Görz, die Umgebungen von Wippach, Adelsberg, Planina, und die Wochein. Jahrb. d. k. k. geol. Reichsanst., vol. 9, 1858, pp. 324-366, 1 pl.

[68] Siegfried Passarge: Die Kalihari, Versuch einer physischgeographischen Darstellung der Sandfelder des südafrikanischen Beckens. Berlin, 1904, pp. 79-80 (C. Die Grundlinien im tektonischen Aufbau Südafrikas).

[69] Hans Simmer: Der aktive Vulkanismus auf dem afrikanischen Festlande und den afrikanischen Inseln. Günther's Münchener Geographischer Studien, No. 18, 1906, p. 24.

ture lines, and that these "run in the entire region often approximately meridional, generally, however, northeast-southwest or northwest-southeast, and only rarely east-west" (see figure 36). These two dominating directions in the diagonal system are strikingly brought out by two strong lines of volcanoes—the Cameroon fissure bisecting the Gulf of Guinea and the Saint Pauls Rocks—Saint Helena line.[70]

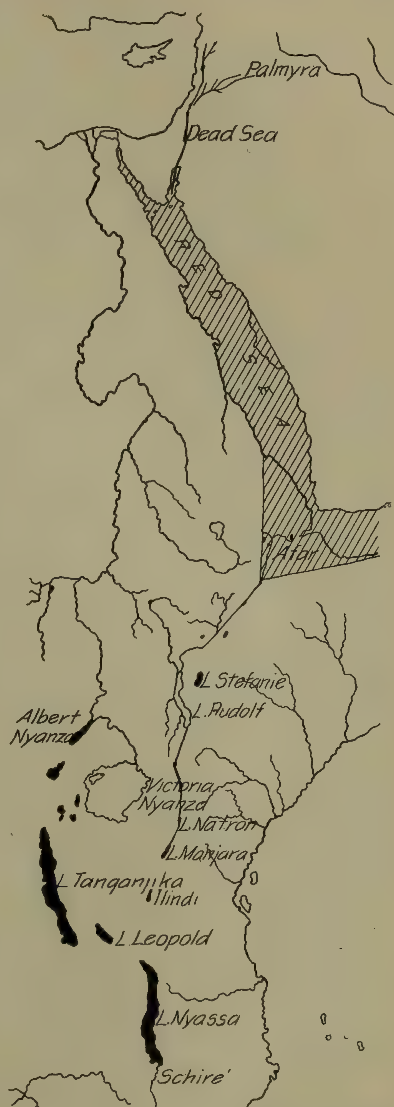

FIGURE 36.—*Oriented Drainage and Structure Lines of East Central Africa*

(After Suess)

THE PRIMARY FRACTURE PATTERN OF THE EARTH'S SHELL

From what has been said in the foregoing sections, it is evident that the repeating patterns of relief and of structure which are encountered in different parts of the same continent, and in different continental areas as well, are in reality but one, of which, however, some of the four component lineament series may locally be either wanting or but faintly indicated (see figure 30, page 157). *This recognition within the fracture complex of the earth's outer shell of an unique and relatively simple fracture pattern, common to at least a large portion of the surface, obscured though it may be in local districts through the superimposition of more or less disorderly fracture complexes, must be regarded as of the most fundamental and far-reaching importance. It points inevitably to the conclusion that more or less uniform conditions of stress and strain have been common to probably the earth's entire outer shell.*

[70] See Proceedings of the American Philosophical Society, vol. 48, 1909, pp. 22-23.

The ultimate cause of this common type of deformation is presumably the continued secular cooling of the planet. It is natural to look for an explanation of the disorderly local fractures in local conditions—such, for example, as the local buttressing effect of relatively rigid rock masses like the Bohemian granite mass within the European architecture—or the position of regions of elevation and denudation with reference to areas of depression and loading. Such essentially local conditions may further explain the considerable variations from complete parallelism between lineaments of the same series either within any fracture field or between distant fields. Noteworthy, however, is the *rectangularity* of the conjugate series within either of the two lineament sets which comprise the pattern.

There has been much discussion as to whether regional joints are tensional or compressional in their nature. To the natural assumption that they are generally compressional and a direct consequence of planetary

FIGURE 37.—*Diagram illustrating the progressive landward shifting of Strand Lines with Uplift due to excessive Depression on the Ocean Floor*

The dotted line is the earlier and the full line the later profile of the surface

contraction, there has been opposed the quite natural objection that being connected directly with mountain-building, the earth's superfices must be locally enlarged, and that tension and not compression is here demanded by the conditions. This traditional difficulty has now been fairly met by recent revelations from the "distant" study of earthquakes. It has been shown that by far the larger proportion—probably at least nine-tenths—of the heavy shocks, and by inference the larger molar displacements of the crust, are suboceanic and connected with depression of the ocean floor. The *local* dilation of the earth's surface, consequent on differential uplift in mountains, must, therefore, be much more than compensated.[71] From this it follows as a corollary that on a rising shore, strand lines should not only be elevated, but should, further, move progressively landward with the uplift (see figure 37).

It has sometimes been a matter of surprise that regional joint systems should have developed in late Pleistocene and in relatively "weak" ma-

[71] Proceedings of the American Philosophical Society, vol. 48, 1909, pp. 27-29.

terials with the same perfection as in more ancient and far more rigid rock-masses.[72] This is probably to be explained by a continuation of the same system of stresses and strains within the earth's outer shell incident to further contraction. Indeed, the study of the Pleistocene deposits of Rügen has shown that block faulting is actually going on in them at the present time.[73] Study of the New England region has likewise shown that the glaciated rock surface has there been faulted in post-Glacial times.[74] The development of a remarkably perfect rectangular joint system within the deposits of an old irrigation basin in the Syrian desert (see plate 12, figure 1) offers evidence favoring the continued development of joint systems into our own times.

Deductions concerning the Nature of Faults

DIFFICULTIES IN THE WAY OF SECURING FAULT MAPS

No study of faults could be considered in any degree adequate which did not recognize that the faults proven to exist by the accepted methods can represent but a small fraction of their actual number. Unlike folds, which are open to inspection or to reconstruction whenever rocks outcrop at the surface, faults by their very nature tend to bury themselves from sight. Since de Beaumont's reckless but convenient use of imaginary faults in order to explain the positions of mountain ranges, the geologist who would guard carefully his reputation has been forced to restrict the use of faults on his maps to those fortuitous larger displacements which may be proven to exist by the observed lack of correspondence of the beds which cross them.

It seems to have been rather generally overlooked that since geologists are required to color in their maps and prepare hypothetical sections where continuous outcrops are not present, as great violence may be done to the facts through the omission of faults which are probably present as by their introduction where they do not exist. The significant fact is that the geological map and section as prepared today call for the representation of the attitude of rock at every point on the surface, whether the necessary data are available or not. It is this difficulty and the way in which it has been met, which accounts for the occasional and seemingly accidental introduction of the fault on geological maps. Theory and experiment are in agreement in indicating that faults, like joints and

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72 G. K. Gilbert: Monograph I, U. S. Geological Survey, 1890, pp. 211-213. Also I. C. Russell: Monograph XI, ibid., 1885, pp. 162-163.

73 Günther: Loc. cit., pp. 58-60.

74 J. B. Woodworth: Post-glacial faults of eastern New York. New York State Museum, Bulletin 107, 1907, pp. 4-28. See also G. F. Matthew: Movements of the earth's crust at Saint John, New Brunswick, in post-Glacial times. Bulletin of the Natural History Society of New Brunswick, No. 12, 1894, pp. 34-42.

folds, seldom occur alone, but rather as elementary parts within series or systems.

In those districts where, because of exceptionally favorable conditions (such, for example, as the occurrence of several thin and easily recognizable but unfolded beds), faults may be identified, small dislocations in great numbers have sometimes been discovered yielding a veritable mosaic of separately moved rock compartments. From the very complexity of these fracture fields, the relatively small individual displacements, but even more the inability to adequately express such structures on the scale of normal geological maps; such areas have seldom been studied in detail, being generally disposed of by the mere statement that they show local faulting with small displacements and, by inference, are of little significance in the tectonics of the province.

THE INHERITED CONCEPTION OF A FAULT

The common notion of a fault would seem to be that it is a disjunctive plane on which the differential displacement begins at one end, increases to a maximum, and finally disappears or dies out on the continuation of the same line. Once found to have disappeared and its hade and maximum throw measured, its character is supposed to be learned.

In earlier studies it was natural that many structures not closely related in origin and not properly correlated, should have been hopelessly confused. Thus it happens that the word fault is generally applied to any disjunctive plane whatever on which differential movement has occurred. Particularly serious confusion has arisen by the inclusion under this term of the flatly sloping thrust-planes which result from local shearing stress within the under limb of a fold *consequent on the folding process.* So-called "normal" or "block" faults, on the other hand, do not appear to be connected directly with folding, at least in the same set of beds, but are produced under wholly different conditions of loading. Yet even today "strike" and "cross" faults are terms in common use to describe faults which are either parallel or perpendicular to the strike direction of the folds. Mechanics teaches us, however, that if faults have been produced by the same system of stresses which induced the folds, instead of being parallel and perpendicular to the strike direction, they should cut diagonally across it.

JOINTS AND FAULTS COMPRISED IN ONE SYSTEM

To Daubrée, the former distinguished geologist of the Natural History Museum in Paris, we owe a great advance over earlier conceptions of faults, for he recognized clearly that certain systems of joints of which,

as he says, "the constancy of the orientation over large areas has already been confirmed," are the *necessary prerequisites* to the formation of faults, adding, "in many countries joints may be seen passing by various intermediaries into faults properly so called." [75]

In the working out of the properties of joint systems a pioneer rôle had already been taken by the early English geologists, especially John Phillips,[76] Samuel Haughton,[77] and Robert Harkness.[78] The dominance of vertical planes, the uniform occurrence of parallel and intersecting series, the subequal space intervals, the so-called "conjugate" rectangular sets of master joints, and, lastly, the similar orientation of any series over broad areas; these are all either recognized or proven in practically all of the papers. Haughton further showed *that there was a system of faults in the district which he studied, and that this was oriented in conformity with the local joint system.* His studies are open to the criticism that he averaged a wide range of joint direction in determining the precise azimuth of each series, but the essentially rectangular intersections of the series is apparent. This elaborate and important pioneer study has been often neglected by later writers on the subject, and it is evident that Daubrée was not familiar with it.

The same dependence of faults on preexisting joints was shown in independent studies made by Brögger in 1884 in the neighborhood of the Langesundfjord in Norway,[79] and by the writer in the Pomperaug Valley of Connecticut in 1899.[80] To quote from the last mentioned paper:

"At the northern end of the eastern Orenaug twin, even smaller dislocations than those just described may be observed. In fact, the dislocations here appear in such numbers and are apparently of such small displacement that they may be properly designated joints. The fracture planes, which are distant only a foot or two from one another, have strikes corresponding with the faults observed elsewhere in the region. There seems, therefore, to be every gradation from faults whose displacement measures hundreds and perhaps a

[75] Daubrée: Géologie expérimentale. Paris, 1879, p. 304.

[76] John Phillips: Observations made in the neighborhood of Ferrybridge in the years 1826-1828. Philosophical Magazine and Ann. Phil., 2d ser., vol. 4, 1828, pp. 401-409. Illustrations of the geology of Yorkshire; part 2, The limestone district. London, 1836, pp. 90-98. Manual of Geology (Etheridge and Seeley edition), London, 1885, pp. 83-84.

[77] Samuel Haughton: On the physical structure of the old red sandstone of the county of Waterford, considered with relation to cleavage, joint surfaces, and faults. Transactions of the Royal Society of London, vol. 148, 1858, pp. 333-348. On the joint systems of Ireland and Cornwall, and their mechanical origin. Ibid., vol. 154, 1864, pp. 393-411. Also Quarterly Journal of the Geological Society, vol. 18, 1862, pp. 403-406.

[78] Robert H. Harkness: On the jointings in the Carboniferous and Devonian rocks in the district around Cork, and on the dolomites of the same district. Quarterly Journal of the Geological Society, vol. 15, 1859, pp. 86-104.

[79] Brögger: Loc. cit., see extract on p. 158 of this paper.

[80] Twenty-first Annual Report of the U. S. Geological Survey, pt. III, pp. 114-115. See also Journal of Geology, vol. 10, 1902, pp. 867-868.

few thousand of feet—the major faults of the basin—through the faults of only moderate displacement which bound the unit blocks of the western Orenaug Hill (estimated to be from 10 to 50 feet), and the small displacements which produce hummocks on the southern slope of the eastern twin (figure 38) to, finally, the prismatic joints, which have just been described from the northern end of the same twin."

EXAMPLE OF A FAULT SYSTEM

The basin of Newark rocks in the Pomeraug Valley has afforded perhaps as satisfactory opportunities for the study of a fault system as is

FIGURE 38.—*Slope of the eastern Twin of Orenaug Hill*

Larger displacements are represented by scarps hidden beneath the fringes of trees on the borders of the block. Smaller faults have outlined the hummocks upon the surface. (Hobbs, U. S. Geological Survey.)

anywhere to be found, and though the area comprises only about 20 square miles, an entire season was devoted to a careful mapping of the system, probably as elaborate a study of the fault structures exhibited by a small area as has thus far been made. The rocks represented are reddish conglomerates and shales with black layers of basalt sandwiched in, the one thin and amygdaloidal, the other heavy and massive though with an upper amygdaloidal surface. All formations have been tilted through a small angle (generally 20 to 30 degrees) and all have, further, been protected from extensive erosion through having been dropped on bounding faults below the level of the surrounding crystalline rocks.

The upper and heavier basalt flow stands out in strong relief, so that its fault structure is largely expressed in the details of the topography. The lower basalt flow is hardly 30 feet in thickness and amygdaloidal, but hav-

ing metamorphosed the underlying conglomerate it is also in relief, can be easily identified and its outcrops followed. Conditions for study could hardly be more ideal. The complex mosaic produced by the faults is well brought out by the outcrops of both basalt layers (see figures 39 and 40). Blocks which are represented on a small scale in figure 40 are, however, each subdivided into many blocks of lower order. Thus the cliff represented at *a a* (figure 40) when studied in detail reveals the complex system of faults which is represented in figure 41, and much the same could be said of each section of the district. A particularly ragged group of fault blocks outlined in basalt toward the north end of the basin has acquired the appropriate name of "Ragland." The appearance here and in the near-by Orenaug Hills the writer has likened to a jam of floating ice-cakes. Along the course of a graben-like canyon, between the last mentioned hills, the fault blocks are well displayed and have been described in the following words (see figure 42):

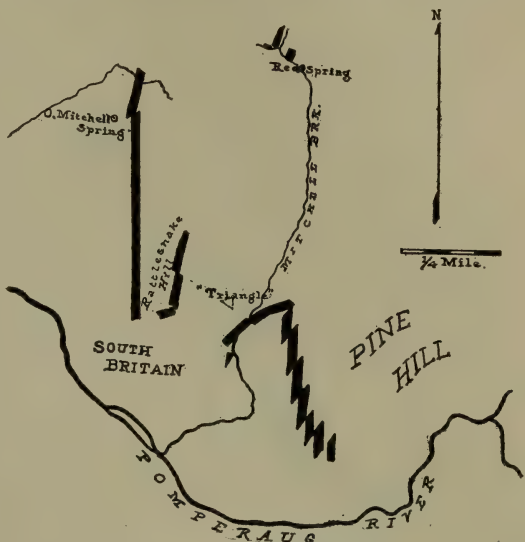

FIGURE 39.—*Effect of Faults in displacing a Basalt Flow*

The arrangement of these fragments of a thin flow of basalt having a flat easterly dip was caused by an elaborate system of faults. South Britain, Connecticut (U. S. Geological Survey).

"In crossing the west twin of Orenaug Hill in a direction from west to east, one encounters cliffs nearly at right angles to the course which are too steep to be scaled. From the top of these cliffs the rock surface, with its thin layer of mold, inclines gently to the eastward to the foot of a similar cliff, to which succeeds a gently sloping summit and a new cliff, as before. Approaching the eastern margin, cliffs appear upon the east, and these soon become the most important ones. If next a start be made at the northernmost point of the basalt in the same hill, where it terminates in a sharp prow between steep cliffs on both the east and west, . . . and a course be taken southward through the intermontane valley, the nearly vertical eastern cliff face, which trends south ± 5 degrees east, can be followed on the right over a quarter of a mile for a portion of the distance in a narrow canyon. After emerging from the canyon the cliff recedes on the right, but its direction is continued in a cliff on

the left. After crossing the highway the path again enters a narrow canyon in the south Orenaug Hill between parallel cliffs to the east and west. For the greater part of the distance that this fault is thus followed, the cilffs are seen to be broken across by faults (north ± 54 degrees east) transverse to the one which is being followed (north ± 5 degrees west). At such points, which occur with great regularity at distances of about 100 paces (about 300 feet), the cliff which has been dwindling rapidly in altitude rises again to near its former height, from which it again falls away before the next cross-fault is reached. It is also noted that alternate faults exhibit a larger throw, determined by the difference in cliff altitudes, and that minor faults are generally to be observed at 50-pace intervals. . . . Where the path enters the canyon between the Twin Hills the same structure is displayed in the cliff facing west, but it is here noted that when the cliff is high on the west it is low on the east, and vice versa—in other words, there is a tendency for the orographic blocks to be upthrown in alternate order corresponding to the black and white squares in a checkerboard. This is certainly more than a local feature, for it can be observed in the main western cliff of the same hill and elsewhere, and the park drive, which ascends the west twin by a very uniform grade from the low southern end, does so by keeping north on the edge of one block until its northern end is reached, then turning sharply across a fault to the block diagonally to the left, and after following this to its end, utilizing the block diagonally to the right, and so on."[81] . . .

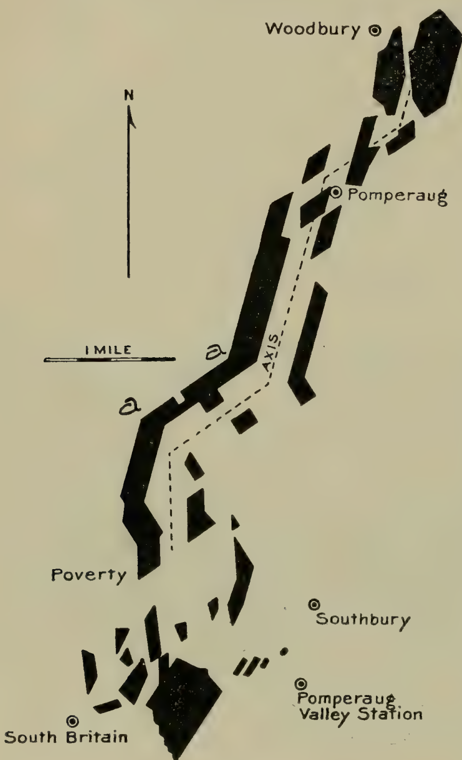

FIGURE 40.—*Fault Blocks represented by Outcrops of the upper Basalt Flow in the Pomperaug Valley, Connecticut*

(Hobbs, U. S. Geological Survey)

The blocks which appear in figure 42 have been called the "unit" blocks of the district because the smallest which could be conveniently mapped, but these group themselves into composite blocks of similar pattern but of larger orders. To quote again:

[81] Twenty-first Annual Report of the U. S. Geological Survey, loc. cit., pp. 107-108.

"While all orographic blocks have in some degree been either elevated or depressed with reference to all of their neighbors of the same order, yet, since the amount of the vertical displacement is different along different fault planes of the same series, with larger throws at regular intervals, it follows that blocks will group themselves into composite blocks of a higher order. Such composite blocks will generally be outlined upon the map, either geologically by the boundaries of exposures of a given formation or in the elevated boundaries of a very resistant formation, or topographically by sudden changes in the profiles of physiographic features. These composite blocks may be of several orders, some of the larger in the Pomeraug Valley being indicated in the serrated eastern boundary." (See figure 29, page 156, and figure 38, page 168.)[82]

A FRACTURE SYSTEM MODEL

To properly represent such an elaborately faulted system as that of the Pomperaug Valley in the form of a model would be a more or less difficult matter in view of the considerable number of fault series there displayed. On the other hand, the elements in the primary pattern which have been above described would involve few difficulties, while bringing out the relation of composite to unit blocks and the nature of displacements. Simplifying this pattern still further by the omission of one set of fractures, as quite often occurs in nature, its more important characteristics may be displayed by a relatively simple model (see plate 13, figure 2). In this model the smallest identifiable fault compartment—the "unit" block—is represented by the smallest unit of the model. Composite blocks of the next higher order, the second, are comprised of four rows of three blocks each. The blocks of the second order, it will be observed, group themselves into three rows of two each for the third order blocks, and these in turn into larger blocks containing similarly three rows of two each. Such a composite structure, if it controls erosion, must develop repeating patterns similar in character to those above described from so many widely separated districts.

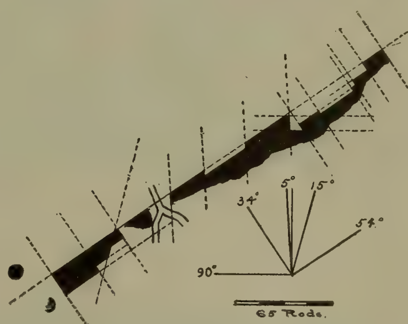

FIGURE 41.—*Details of Faulting along Front of Basalt Cliff shown at a a in Figure 40*

(Hobbs, U. S. Geological Survey)

SUDDEN CHANGES OF THROW ON FAULTS

If the above described model correctly represents the nature of a patterned fault system, which is itself made up from and is a part of the

[82] Twenty-first Annual Report of the U. S. Geological Survey, loc. cit., pp. 110-111.

joint system of the district, important deductions may be made relating to the nature of the displacement on individual faults. Among the many faults represented on the model, let us confine our attention for the moment to the most important—that which divides the main block longitudinally on a medial line. The throw on this fault does not begin with a small value, increase gradually to a maximum, and then die out gradually; on the contrary, it is subject to the most abrupt changes, amounting even to reversal of the thrown limb at points where the fault passes from the end of one pair of blocks to the beginning of the next. Near the center of the model the throw has been reduced to nothing, and on the

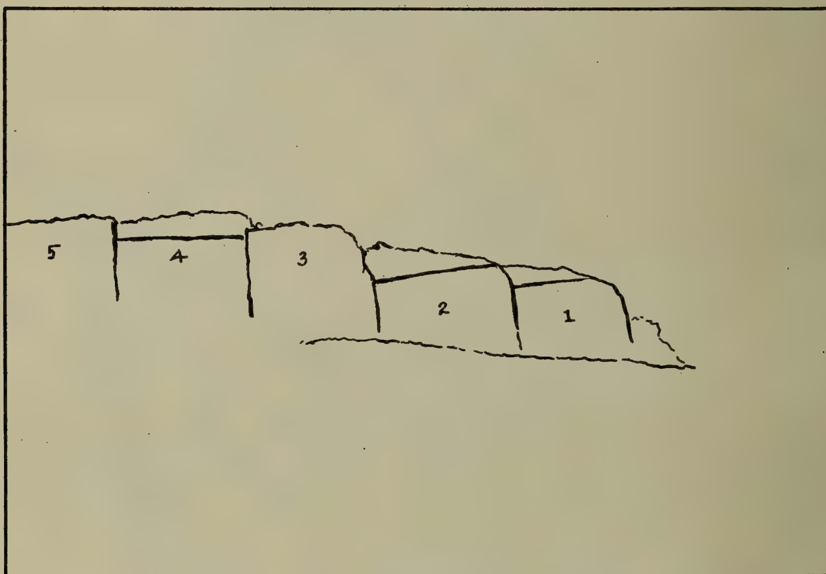

FIGURE 42.—*Floating Block Topography of the Orenaug Hills, near Woodbury, Connecticut*

(Hobbs, U. S. Geological Survey)

traditional conception might be thought to have come to an end; but a little farther on it quite as suddenly takes on values which approach the maximum. Reversals of the thrown limb are exhibited near the middle of the section of the fault. It will be noted that the abrupt changes occur where cross-faults intersect and where in consequence streams are likely to be located.

EVIDENCE FURNISHED BY EARTHQUAKES

Until quite recently faults had been studied in the field only where in part disclosed through denudation processes, and the opportunity to

FIGURE 1.—STREAM CONTROLLED BY JOINT STRUCTURE

This stream has its course controlled by joint structures, as is well displayed in the canyon walls. Frybro, Gudbrandsdalen, Norway. (After a photograph by Knudsen, of Bergen)

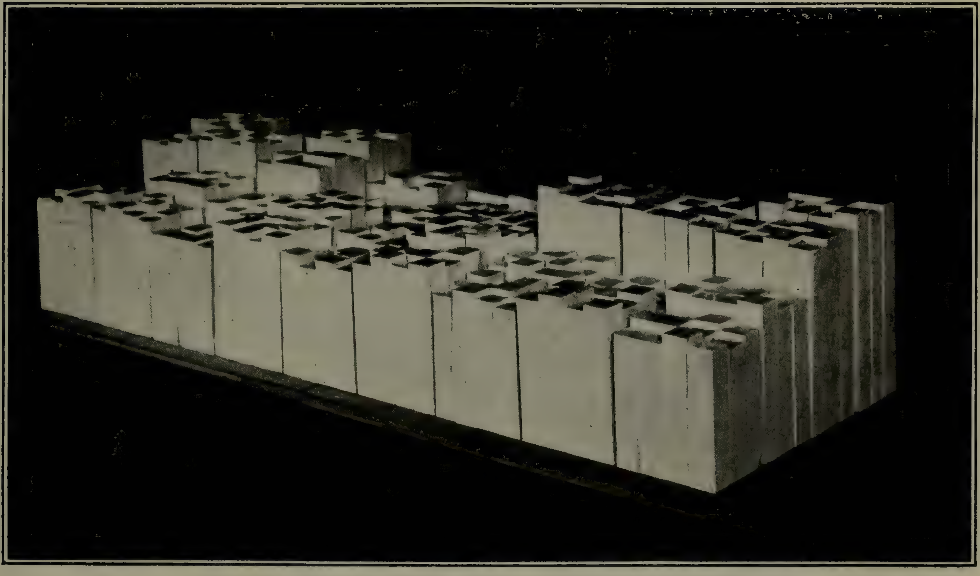

FIGURE 2.—MODEL ILLUSTRATING BLOCK MOVEMENTS WITHIN A FAULTED DISTRICT WHICH EXHIBITS ELEMENTS OF THE PRIMARY PATTERN

Composite blocks of three different orders are shown, as are also the variations in throw on faults, best on the large medial fault of the model

AN EXAMPLE AND A MODEL OF A FRACTURE PATTERN

measure the actual vertical displacement was limited to those relatively rare localities where offsetting of beds was observable on the fault-plane. The faults which appear at the earth's surface at the time of an earthquake were until recently regarded as a consequence rather than a cause of the earth's shocks, and hence they were not regarded as true dislocations within the earth's shell comparable to those uncovered by extensive denudation. So soon as they are recognized as elements within the earth's fracture system, they may be appealed to for information concerning those properties of a fault not often revealed under other circumstances.

Now, it is a fact of much significance that all "earthquake faults" disclose the same abrupt changes in vertical displacement which are indicated on the faults of the above described model, as well as by the faults of the Pomperaug Valley.

The first earthquake fault to be carefully studied, if we except the one formed in New Zealand in 1855 and mentioned by Lyell in his *Prin-*

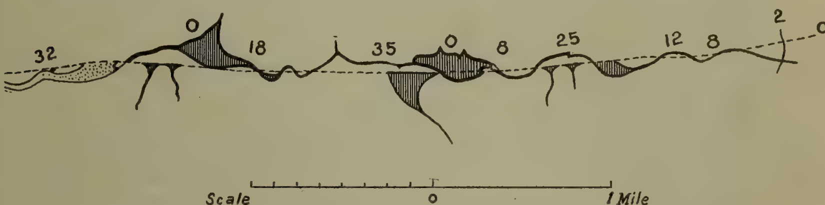

FIGURE 43.—*Map of the Chedrang Fault*

The faults opened in Assam on June 12, 1897. The vertical displacements are shown at different places along the course of the fault. (After Oldham)

ciples,[83] was that opened in the Neo Valley, Japan, in 1891, of which the beautiful photographs published by Milne and Burton[84] attracted at the time considerable attention. Kotô[85] tells us that at Katabira the east side of the fault was downthrown. At Midori, five kilometers farther north, the *west* side was the one downthrown and by the maximum amount (about 18 feet), which was anywhere observed on the entire length of the fault. Again, at Itasho, about one and a half kilometers farther north, the downthrow was once more on the east side.

The Baishiko fault, which was opened in Formosa during the earthquake of March 17, 1906, showed a similarly abrupt change in vertical displacement. At Bisho, near the east end of the fault, the north limb was downthrown 6 feet, whereas to the west, two-thirds of a mile at

[83] Vol. 2, pp. 82-89.

[84] The great earthquake of Japan. Yokohama, 1891, pp. 1-10, 39 pls. and map.

[85] On the cause of the great earthquake of central Japan. Jour. Coll. Sci. Imp. Univ. Tokyo, vol. 5, 1893, pp. 339-340, pl. 29.

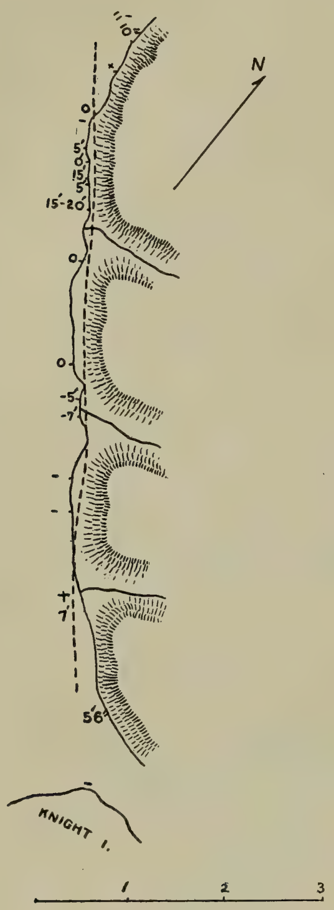

FIGURE 44.—*Changes of Throw measured on the Course of a Fault near the Shore of Russell Fjord, Alaska*

This fault opened in September, 1899. (After Tarr and Martin)

Kaigenko, it was the south limb which was downthrown and by approximately the same amount.[86]

The same holds true of the faults of the Owens Valley, California, either opened or increased, during the great earthquake of 1872. At a point a mile south and a little east from Diaz Lake, as is shown by the beautiful maps and views prepared by Johnson,[87] the vertical downthrow here changes most abruptly from the eastern to the western limb of the fault.

Two additional instances may be cited which especially well illustrate the abrupt changes in vertical throw on earthquake faults. The Chedrang fault, opened in Assam during the great earthquake of 1897, offers one of the grandest examples of an earthquake fault that has thus far been studied. The throws, measured in feet, here uniformly applying to the upthrown limb, are given after Oldham[88] on the map reproduced in figure 43. As one goes from north to south along the course of the fault the displacements, measured in feet, read in order: 32, 0, 18, 35, 0, 8, 25, 12, 8, 2, 0.

Perhaps even more interesting and significant are the throws on the fault which was opened near the shoreline of Russell Fjord, Alaska, in September, 1899; since here the cross-valleys seem to represent roughly the dividing lines between consecutive fault blocks (see figure 44).[89]

[86] Omori: Preliminary note on the Formosa earthquake of March 17, 1906. Bulletin E. I. C., vol. 1, No. 2, pl. 17.

[87] The earthquake oi 1872 in the Owens Valley, California. Beiträge zur Geophysik, vol. 10, 1910, pp. 378-379, pl. 17B.

[88] R. D. Oldham: Report on the great earthquake of June 12, 1897. Memoirs of the Geological Survey of India, vol. 30, pl. 42.

[89] Tarr and Martin: Recent changes of level in the Yakutat Bay region, Alaska. Bulletin of the Geological Society of America, vol. 17, 1906, pp. 50-64, pl. 23, fig. on p. 53.

Here the figures are read from the datum of sealevel in feet, and their order from northwest to southeast is: + 11 feet, 10 inches; +; 0; —; + 5 feet; 0; + 15 feet; + 5 feet; + 15 to 20 feet; stream valley; 0; 0; — 5 feet (near stream); stream valley; — 7 feet; —; —; stream valley; +; + 7 feet; + 5 feet, 6 inches; small fjord; —. Submergencies of the coast are here usually indicated by the minus sign without accompanying figures, for the reason that it is difficult to measure the displacement when the strandline is no longer visible. The authors of the report on this earthquake say:

"It (the uplift, editor) was complicated by movements along secondary fault lines, which produced at least three (and perhaps more) distinct major blocks. . . .

"Accompanying this faulting was a minor fracturing apparently due to local adjustments in the tilted blocks. Doubtless this minor fracturing is much more common than our observations indicate, for it was discovered on more than half of our expeditions into the interior when we went out of the valleys away from the seacoast." [90]

Conclusion and Request

The most important conclusion growing out of this study of relief and fracture patterns throughout wide areas, is that there exists a primary fracture pattern produced from two bisecting rectangular sets of fractures, each made up of two series of parallel fracture planes subequally spaced and vertical. Within this primary pattern are comprised both the joint and fault systems as similar parts, the individual faults differing from the joints in scale only, the displacement being measurable only on the fault, and the fault pattern being in like manner distinguished from the elementary joint pattern by its generally larger scale or order.

Owing to the occurrence of somewhat wider joint spaces at regular intervals within each series, the joint pattern is composite, or made up of similar repeating units of several groups or orders. Locally in both joint and fault patterns, certain of the series are either lacking or but poorly developed, and locally, also, both patterns may be almost hopelessly confused by additional and disorderly fractures which seem to defy arrangement within any system. Lastly, the relief pattern of the earth's surface is to a large extent controlled by the fracture pattern, though locally the strong and weak beds of plunging folds may exert an even stronger influence.

All are agreed that the process of denudation is set in operation by epeirogenic movement—differential uplift of the surface—which may thus

[90] Loc. cit., p. 63.

be said to measure the amount of denudation, modified, however, by rock composition and texture. Similarly, the rock folds and the fractures are produced by what we commonly call orogenic movement—the tangential rather than the vertical component of earth stresses—and the degree of deformation resulting is, therefore, measured in terms of these forces. Just as the positions of individual folds depend on inherent existing structures—initial dip, thickening of formation, etcetera—so *the localization of the zones of excavation by the denuding agents which attack the surface is fixed by fracture structures already existing at the time*—a fact of the first importance and one strangely overlooked by the modern American school of geomorphology.

Carrying our analogy one step further, the *shape* of the folds—whether open or closed, symmetrical or overturned—will be determined largely by the nature of the rock layer and by the stage of the process of deformation. So, too, it can not be too strongly emphasized that the *shaping* of the erosion surface is an expression of the nature of the rock, the agent of excavation, and the stage which has been reached in the process. It is, however, largely independent of the *position* of valleys in the plan. The conditions of the shaping may be largely read in the *landscape* patterns—the character profiles; the position of valleys, on the other hand, in the *relief* patterns brought out on the map.

As already stated, the present paper is a summary made from a larger study on which the writer has been engaged for a number of years. He would greatly appreciate and gratefully acknowledge the communication of facts or the reference to literature which bears on the subject. It is suggested that studies of local relief in relation to fracture structures made under proper oversight are eminently adapted for assignment to students as thesis problems.[91]

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[91] See Harder, loc. cit., and Lind, loc. cit.

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PRE-GLACIAL COURSE OF THE UPPER HUDSON RIVER[1]

BY WILLIAM J. MILLER

(*Presented before the Society December 28, 1910*)

CONTENTS

INTRODUCTION

It is the purpose of this paper to show that the major drainage features of the southeastern border of the Adirondacks have been well nigh revolutionized as a result of the presence and retreat of the Pleistocene ice-sheet. The region under discussion lies in Warren, Saratoga, and Fulton counties and is represented by the accompanying sketch map. For a proper understanding of the points involved the reader should consult the State geologic map and the following topographic sheets of the United States Geological Survey: North Creek, Bolton, Stony Creek, Luzerne, Glens Falls, Broadalbin, Saratoga, and Schuylerville.

The remarkable courses of the Hudson and Schroon rivers, as well as certain tributaries, have long been recognized. As stated by Kemp and Newland:[2] "There is a peculiar tendency of the streams to leave the normal southerly courses and double back on themselves to the northeast again. . . . The Sacandaga makes a very acute angle with its old

[1] Published by permission of Dr. J. M. Clarke, State Geologist of New York. Manuscript received by the Secretary of the Society January 7, 1911.
[2] Seventeenth Annual Report of the New York State Geologist, p. 510.

direction, and the Hudson behaves in an almost identical way, although it later resumes a southerly course." No study of the subject, however, was

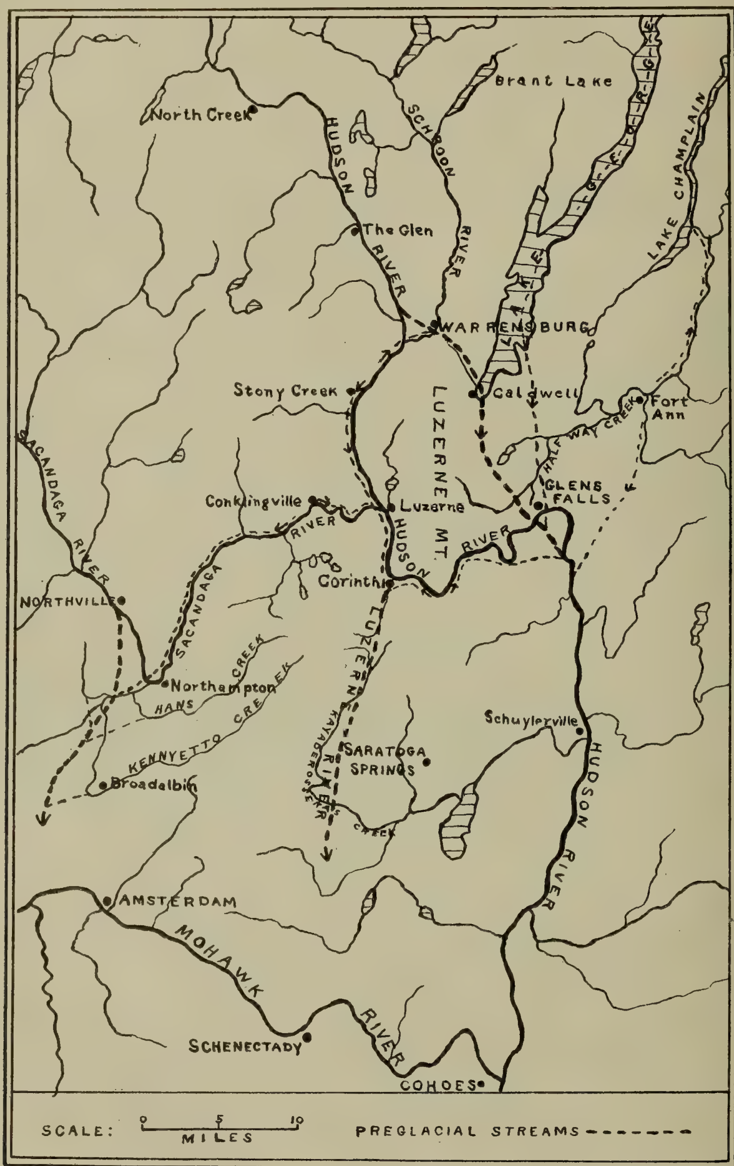

FIGURE 1.—*Sketch Map of the southeastern Adirondack Region*

Showing the relation of pre-Glacial drainage to that of the present. Pre-Glacial courses shown only where essentially different from present streams

attempted by these authors. During pre-Glacial time the principal streams of the region had become thoroughly adjusted to the geologic structure and topography, and even a casual examination of the maps shows that the two distinct embayments of Paleozoic rocks, which produce valleys extending northward into the Adirondack mass, must have contained important streams which drained normally southward out of the mountains. The post-Glacial course of the Hudson River across the Luzerne range between Corinth and Glens Falls has been touched on in a paper by G. F. Wright.[3]

The Hudson River

POST-GLACIAL COURSE

Between North Creek and Warrensburg, as will be shown below, the Hudson River follows essentially the same general course as during pre-Glacial time. From Warrensburg to Glens Falls, however, the course of the Hudson is wholly post-Glacial. That the pre-Glacial Hudson did not cross the Luzerne quadrangle is clearly shown by the existence of a pre-Glacial divide where the great gorge of the Hudson is now located, just above Stony Creek station on the Delaware and Hudson River Railroad. This gorge, well shown on the topographic map, has a length of about 3 miles and a maximum depth of about 1,200 feet, the river here being at an altitude of 600 feet, while the highest points immediately on either side rise to nearly 1,800 feet. This is the most striking example of a gorge in the whole region under discussion and is quite certainly of post-Glacial origin. It affords a fine illustration of a "through valley," to use the term of Professor Davis.

Some of the stronger evidences favoring the existence of a pre-Glacial divide near Stony Creek are as follows: The deep narrow gorge of recent origin; the flaring of the channel both northward and southward from the deepest part of the gorge, which is just what would be expected in the case of a divide with drainage in both these directions; the anomalous turns of both the Hudson and Schroon rivers towards the southwest in the vicinity of Warrensburg, which is scarcely to be expected, because, instead of swinging southwestward to cut a channel through the highland country in the northern portion of the Luzerne quadrangle, an easier and more natural course might have been found towards the southeast, across the much lower land between Warrensburg and Lake George; the tendency of the tributaries between Warrensburg and the gorge to double back on their courses; the existence in the gorge of hard gneisses rather

[3] Science, November 22, 1895, p. 675.

than soft Grenville rocks, which are so common farther northward, and the apparent lack of faulting and the fact that the course of the river is nearly at right angles to the strike of the foliation, whereas faulting and foliation have elsewhere in the region been important factors in determining stream channels.

Between Corinth and Glens Falls the Hudson cuts across the Luzerne Mountain, and, as shown by Wright in the paper above cited, this course is certainly either inter-Glacial or post-Glacial in origin. This matter may be discussed to better advantage below in connection with the Luzerne River.

PRE-GLACIAL COURSE

That the pre-Glacial Hudson, between North Creek and Warrensburg, flowed in practically the same direction as at present is shown by the fact that it occupies a broad general depression, which is in harmony with the character and structure of the rock-masses.[4] This broad depression is characterized by an abundance of weak Grenville gneisses, through which protrude more resistant masses of syenite or granite. Other important factors of drainage control here are the extensive faulting and the strike of the foliation, both of which are in general north and south. Also, it should be stated, that distinct highland masses preclude the possibility of any other than a southward course of the pre-Glacial Hudson across the North Creek sheet. Below Warrensburg, however, the pre- and post-Glacial courses of the Hudson are very different. It has already been shown that the pre-Glacial Hudson did not flow across the Luzerne quadrangle, and it now remains to locate its pre-Glacial channel elsewhere.

Between the Hudson-Schroon River and the Lake George depression there is a highland belt or mountain ridge which, towards the south, is known as the Luzerne Mountain. The pre-Glacial Hudson must have crossed this mountain ridge, and there appear to be but two possibilities for an old channel here. One of these is the depression which strikes northwest-southeast between Warrensburg and Caldwell, while the other runs nearly east and west between Warrensburg and Hillview (on Lake George).

Some of the considerations favoring the Warrensburg-Caldwell channel are: (1) Lower elevation (not over 840 feet) of the divide in this depression; (2) the nearness (1¼ miles) of this divide to the Schroon-Hudson river bottom and its distance from Lake George, which is what would be expected, because a river flowing southeastward through this

[4] Some interesting drainage changes in the course of the Hudson above North Creek have been described by Prof. J. Kemp in "The Physiography of the Adirondacks." Popular Science Monthly, March, 1906, pp. 205-206.

channel would necessarily be at a higher level near the Warrensburg end; (3) the decidedly unfavorable direction of the depression for ice erosion and the existence of so much rotten rock even well down in the depression, both prove that this passage is now essentially as it was just before the Ice Age, and this in turn means that it must have been the lowest passageway across this highland belt; (4) the harmony of this channel with the rock structures—as, for example, the strike of foliation of the gneisses and the strike of a fault—which quite certainly has developed a line of weakness through the ridge here; (5) the very direct course of such a channel affording a natural outlet for the Hudson from the Adirondack highlands, and (6) the perfect continuation of this channel through a low and distinctly drift-filled depression just west of French Mountain and south of the end of Lake George.

Some of the considerations unfavorable to a Warrensburg-Hillview channel are: (1) The higher elevation (nearly 900 feet) of the divide in this depression; (2) the nearness of the present divide to Lake George; (3) the more favorable direction of this depression for ice erosion, and the fact that where exposed the rock is comparatively fresh go to show that this depression was not so low just prior to the Ice Age; (4) the lack of harmony with rock structures here; (5) the more indirect course of a channel through this depression, and (6) the probable continuation of such a channel across what is now a shallow part (as shown by the islands) of Lake George, and thence to the east side of French Mountain.

Emphasis should be laid on the fact that the pre-Glacial course of the Hudson, here accepted by the writer, was in perfect harmony with certain major topographic and structural features. A normal fault of very considerable displacement exists along the west side of Lake George towards the south end, as proved by the fact that Paleozoic rock near the lake level comes sharply against the pre-Cambrian of the highlands just to the west. Due to the more rapid wearing down of the softer Paleozoics on the east side of the fault during pre-Glacial time, a prominent depression was developed, which continued for some miles southward and to the west of French Mountain. Thus the pre-Glacial Hudson followed rock structures (foliation and fault) from Warrensburg to Lake George, and after crossing the great fault continued southward in adjustment to rock structure by following the fault depression (now deeply drift-filled) just west of French Mountain and then emerged on the Paleozoic lowlands towards Glens Falls. Thus, while the possibility of a pre-Glacial Hudson River channel just east of French Mountain is admitted by the writer, the best evidence is thought to be against it.

The pre-Glacial Hudson was joined by the Schroon River just east of

Warrensburg, while a short tributary, having its source on the Stony Creek divide, flowed northward to enter the Hudson.

DRAINAGE OF LAKE GEORGE DEPRESSION AND EASTWARD

The drainage history of this portion of the region has been ably presented by G. F. Wright, and also by J. F. Kemp, in the papers above mentioned, and a very brief summary of that work is here given because of its relation to the present discussion. The heavy drift accumulation from Glens Falls northward has had much to do with the development of the present drainage, especially as seen in the remarkable course of Half Way Creek, which, though it has one of its sources in the city of Glens Falls and close to the Hudson River, flows northward into Lake Champlain. Wright believes the pre-Glacial division of drainage between Lake Champlain and the Hudson was near Fort Ann. He also believes that a pre-Glacial divide existed at the narrows in Lake George, and that the south-flowing stream from this divide went through Dunham Bay and to the east of French Mountain. According to the present writer, this stream, and also the south-flowing one from the Fort Ann divide, were tributary to the pre-Glacial Hudson in the vicinity of Glens Falls.

INFLUENCE OF ICE EROSION

The elevation of the present Hudson River west of Warrensburg is about 620 feet, while its elevation when it passed through the pre-Glacial channel southeast of the village was about 840 feet. This difference in altitude of the channels must be accounted for either by inter-Glacial or post-Glacial stream erosion or by ice erosion. While it is more than likely that both of these processes have been effective, we shall now consider only the influence of ice erosion. There is good evidence for vigorous ice erosion of the Hudson Valley in the vicinity of Warrensburg, and some of the facts favoring this view are as follows: (1) The great abundance of scratched, polished, and rounded rock surfaces; (2) the comparative freshness of the rock, even in the case of the weak Grenville; (3) the unusual softness and weakness of much of the pre-Cambrian rock here due to the existence of extensive belts (forming valleys) of thin-bedded, variable Grenville sediments; (4) the fact that these belts of weak rocks must have been deeply decomposed during the long pre-Glacial time, thus favoring extensive removal of material, and (5) the north-south movement of the ice being parallel to these Grenville valleys, and hence very favorable to ice erosion.

We have in this region a good illustration of differential ice erosion, because in the channel southeast of Warrensburg the unusual abundance

of decayed rock proves the ineffectiveness of ice erosion. The movement of the ice was directly across this depression, and hence not conducive to erosion. This case stands out in marked contrast to the area of vigorous ice erosion immediately westward along the Hudson-Schroon rivers.

That ice erosion was more or less effective in lowering the pre-Glacial divide at Stony Creek seems certain. The direction of ice-flow was almost exactly parallel to the present direction of the gorge, thus decidedly favoring erosion. Also the cutting power was increased because of the great depth of ice due to its concentration in this the lowest portion of the broad general depression of the northern part of the Luzerne quadrangle. How much of the depth of the gorge is due to ice erosion can not be stated.

The Lake George depression was doubtless considerably deepened by ice erosion due to the passage of the deep, concentrated ice of the Champlain-Mohawk lobe (see below). The comparatively weak Paleozoic rocks along the fault in the southern portion of this depression must have yielded pretty readily, and hence the pre-Glacial channel of the Hudson along here was doubtless considerably lowered by ice erosion. Thus the present brook, which empties into Lake George and which occupies the channel between Warrensburg and the lake, is much swifter than was the pre-Glacial Hudson along this course.

CAUSE OF PASSAGE OF THE HUDSON OVER THE STONY CREEK DIVIDE

While it may be possible that ice erosion alone was sufficient to cut down the Stony Creek divide so as to allow the passage of the Hudson after the withdrawal of the ice-sheet, this seems highly improbable, and, at least, there is no positive proof for such a belief. However, it is now well established by the early work of Chamberlin, and by the more recent work of Brigham[5] and others, that during both the advance and retreat of the ice a distinct lobe occupied the Champlain-Lake George depression and extended around into the Mohawk Valley. Thus, when the Lake George ice-lobe was still present, the pre-Glacial course of the Hudson was completely blocked and the Hudson-Schroon River drainage immediately to the west was forced to take a new direction. The natural passageway for this drainage was over the Stony Creek divide, which had already been somewhat lowered by ice erosion. If there was more than one advance and retreat of the ice, as strongly suggestive evidence (given below) seems to indicate, there may well have been considerable gorge cutting by stream erosion during inter-Glacial time, and in this case the

[5] "The Mohawk glacial lobe," a paper read at the Pittsburgh meeting of the Geological Society of America, 1910.

first passage of the river over the Stony Creek divide probably occurred before the last advance and retreat of the ice-sheet.

The Sacandaga River

The Sacandaga River, like the Hudson, shows a remarkable tendency to turn back on its course. On emerging from the Adirondack highlands this stream enters a broad Paleozoic rock valley at Northville and continues its course to Northampton, where it makes a sharp turn northeastward to cross a broad tongue of hard pre-Cambrian rock, flowing past Conklingville and into the Hudson at Luzerne. As shown on the accompanying map, certain tributaries of the Sacandaga, like Kennyetto and Hans creeks, also show striking tendencies to flow back on their courses before entering the main stream. The drainage problem involved will be touched on briefly because of its relation to the Hudson River history.

It is certain that the pre-Glacial Sacandaga flowed southward past Gloversville through the broad Paleozoic rock valley and into the Mohawk River. This must have been the normal drainage as a result of stream adjustment during pre-Glacial time, since such a course was in perfect harmony with the topography and rock structures. Kennyetto and Hans creeks were tributary to this south-flowing Sacandaga. At or near Conklingville there was a pre-Glacial divide, as shown especially by the perfectly aggraded condition of the channel westward and southwestward from Conklingville and by the distinct flaring of the valley westward from Conklingville. An important tributary (which we may call Batchellerville Creek) of the pre-Glacial Sacandaga had its source on the Conklingville divide and flowed westward and then southwestward through a great fault trough past the village of Batchellerville and into the Sacandaga near Northampton, thus offering a fine example of reversal of drainage for some 15 or 16 miles between Northampton and Conklingville.

The cause of the deflection of the Sacandaga across the Conklingville divide seems quite clear. Professor Brigham,[6] who has made a careful study of the Pleistocene geology of the Broadalbin quadrangle, has shown that a prominent interlobate moraine extends across the southern end of the great Paleozoic embayment past Broadalbin and Gloversville. This moraine has blocked the southward course of the river, which has thus been forced to seek the lower outlet across the divide at Conklingville.

The Luzerne River

Thus far we have shown that the pre-Glacial Hudson did not flow southward across the Luzerne sheet, and also that the pre-Glacial Sacan-

[6] New York State Museum Bulletin No. 121, pp. 21-31.

daga did not have its present course past Conklingville. It now remains to describe an important pre-Glacial stream (now extinct as such), which did drain most of the area of the Luzerne quadrangle. This stream, which the writer would call the Luzerne River, had its source on the south side of the Stony Creek divide and flowed southward past the villages of Luzerne and Corinth. As far as Corinth it occupied almost exactly the same course as the present Hudson. From Corinth it passed southward through the broad Paleozoic rock valley (now occupied by Kayaderosseras Creek) and to the west of Saratoga Springs. Beyond this its course has not been traced on account of the heavy drift.

Wright[7] showed that in pre-Glacial time no stream crossed the Luzerne Mountain between Corinth and Glens Falls, and with this view the writer is in perfect accord. However, in Wright's paper, the pre-Glacial divide at Stony Creek was not recognized, and hence it was quite naturally assumed that the pre-Glacial Hudson flowed past Luzerne and Corinth and thence southward through the Kayaderosseras Valley. Wright explains the passage of the Hudson across Luzerne Mountain as due to heavy drift filling south of Corinth, and the writer believes that this explanation, which is practically the same as that given to account for the deflection of the Sacandaga, is certainly correct. The important point of difference between Wright's paper and the present one is that the pre-Glacial Hudson did not flow southward across the Luzerne and Saratoga sheets, but that the now extinct Luzerne River rising on the Stony Creek divide took this course.

A pre-Glacial divide was somewhere near Spiers Falls dam, which is about 4 miles below Corinth on the Hudson, and a short westward-flowing stream from this divide was tributary to the Luzerne River near Corinth, while an eastward-flowing stream emptied into the pre-Glacial Hudson.

A short tributary of the Luzerne River flowed eastward from the Conklingville divide.

Glacial Lake Warrensburg

This extinct lake, here described briefly for the first time, has a certain important bearing on the drainage history of the region. The lake has been so named because of the location of the village of Warrensburg on the old lake deposit, which is especially well shown as a flat-topped sand area between the village and the Hudson River. The concordant altitudes of the sand flat where unaffected by subsequent erosion, the remarkable freedom of the surface from boulders, and the crudely stratified character of the material as shown in cuts, all afford conclusive evidence for static

[7] Op. cit., pp. 674-675.

water conditions here. The line of contact of this lake at its height with the surrounding land is pretty accurately shown by the 760-foot contour line, but because of post-Glacial changes of level in this region the writer can not state the elevation of the lake surface above sealevel. The lake deposit has been deeply trenched by both the Hudson and Schroon rivers, and as a result of the cutting down process many fine terraces have been formed. The main body of water showed its greatest width of about 3 miles on a line passing east and west through Warrensburg. However, clearly defined sand terraces, the highest of which always rise close to the 760-foot contour line, prove that important arms of this lake extended nearly 8 miles above Warrensburg along the Schroon River, nearly 4 miles up the Hudson above the mouth of the Schroon, 1½ miles up Patterson Brook, and at least 2 miles down the Hudson from the mouth of the Schroon.

In the vicinity of Warrensburg, and especially up the Schroon River, the lake deposits, though deeply trenched, have seldom been cut through to the underlying rock. In the Stony Creek gorge there are good sand terraces considerably lower than 760 feet, and these are probably connected with the deposits of a Glacial lake (not studied by the writer), which extended down the Hudson and over the region around Corinth. The channel throughout the Stony Creek gorge is mostly, if not entirely, filled with sand and gravel deposits. Where the Sacandaga crosses the pre-Glacial divide at Conklingville the channel is filled with loose sediment, borings by the New York Water Supply Commission showing a depth of over 200 feet before striking rock.

The writer believes that these examples of channels filled with loose sediment afford a strong argument in favor of more than one advance and retreat of the ice in this part of the State. On the basis of a single advance and retreat of the ice, it seems necessary to assume that the deep narrow gorges at Stony Creek and Conklingville were produced entirely by ice erosion, and this seems highly improbable, especially in the case of Conklingville, where the direction of ice-flow was decidedly unfavorable for any considerable ice-cutting. A far more reasonable explanation allows for a large amount of stream erosion in the production of the gorges. Thus the gorges most likely attained much of their depth by stream erosion during inter-Glacial time, and during the final retreat of the ice these channels were more or less choked with loose sediments, which the streams have been unable to completely remove during the short post-Glacial time. Such inter-Glacial stream erosion, combined with ice erosion, as above explained, also satisfactorily explains why the Hudson and Schroon River channels at Warrensburg are so much lower than the pre-Glacial Hudson channel between Warrensburg and Caldwell.

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AGGRADED LIMESTONE PLAINS OF THE INTERIOR OF BAHIA AND THE CLIMATIC CHANGES SUGGESTED BY THEM [1]

BY J. C. BRANNER

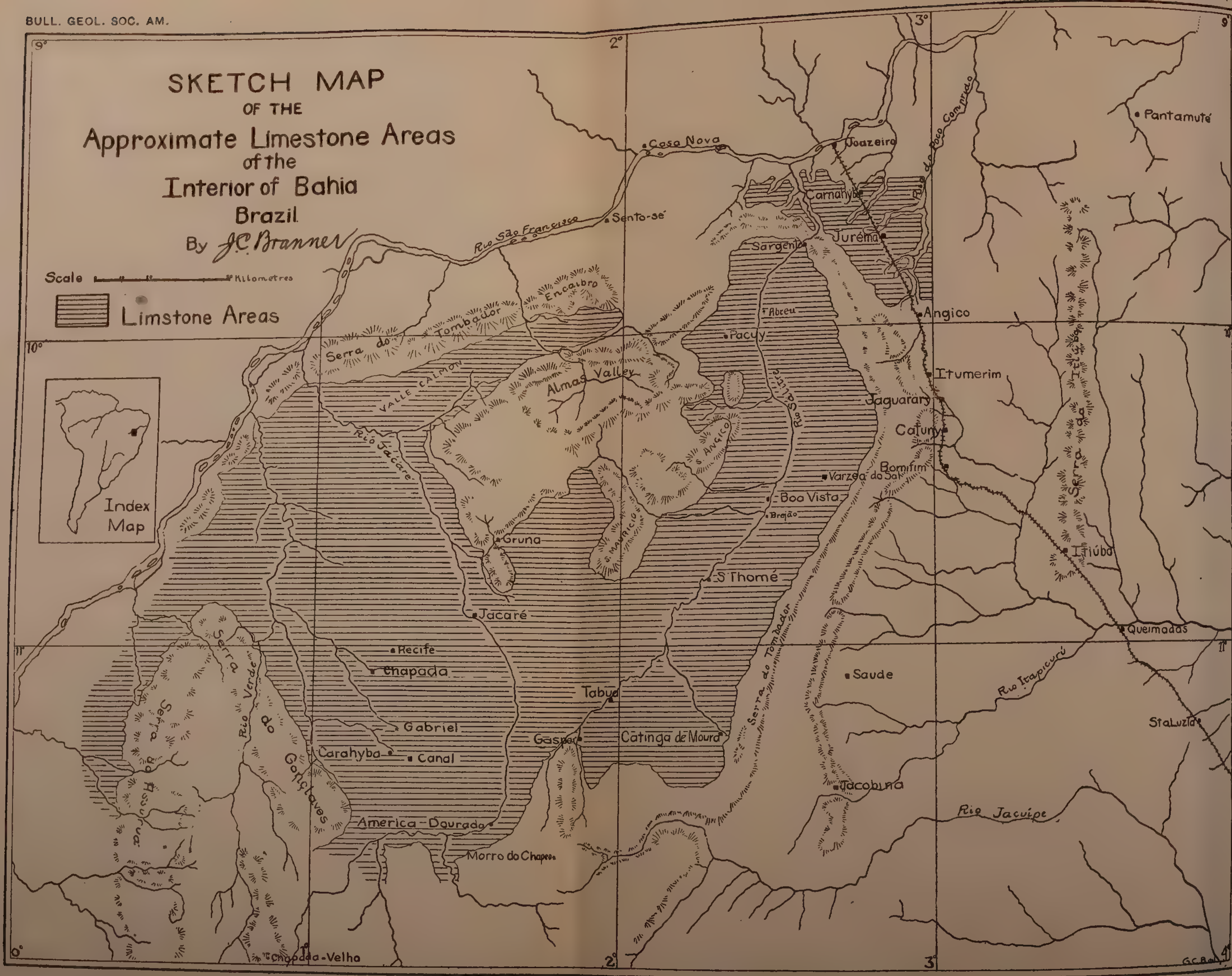
(Presented before the Cordilleran Section March 25, 1910)

CONTENTS

Geological Map

The accompanying geological sketch map shows a large area of limestone in the interior of Bahia. The limestones of the region, however, are not all represented on the map, and no attempt is made to show them in detail. This lack of detail is partly due to the scale of the map, which does not admit of it, and it is partly owing to the fact that their exact distribution has not been worked out over any considerable part of the region.

[1] Manuscript received by the Secretary of the Society April 4, 1911.



LIMESTONE AREAS OF THE INTERIOR OF BAHIA, BRAZIL

The geologic relations of the Bahia limestones to the other rocks of the State will be seen in the following tentative table of the general groups or divisions of the rocks:

Geologic Divisions of the State of Bahia

Divisions	Thickness in meters	Ages
Catinga limestones	10	Tertiary to Recent.
Taboleiro series	200+	Tertiary.
Sergipe series	300+	Cretaceous
Salitre limestones	350	Jura ?
Estancia red beds	350	Trias ?
Lavras series	700	Carboniferous ?
Cambão quartzites	100	(Probably part of Lavras series.)
Caboclo shales (possibly the Paraguassú of Derby)	500	Devonian ?
Jacuipe flints	100	(Probably part of Caboclo series.)
Tombador sandstones	400	Silurian ?
Minas (or Jacobina series)	1,000	Cambrian ?
Crystalline complex		pre-Cambrian ?

It will be noted that the ages of all the divisions below the Cretaceous is questioned. The ages here suggested for the doubtful divisions are based on physical breaks and differences, and are subject to revision. In connection with the principal subjects of the present paper, the ages of these divisions are of no especial importance save in the case of the Catinga deposits.

The Limestone Horizons

Limestones are found in four of the divisions given in this table. Beginning with the oldest, these are:

1. White marbles in the crystalline complex, supposed to be pre-Cambrian.

2. Blue and gray limestones and marbles in the Salitre limestone series, believed to be Jurassic.

3. Gray and cream colored limestones in the Sergipe series, of Cretaceous age.

4. The Catinga limestones of recent origin, but probably beginning in the Tertiary.

Farther up the valley of the Rio São Francisco there is another limestone of Silurian age at Bom Jesus da Lapa,[2] and it is quite possible that some of the limestones here set down as Salitre belong with the Silurian beds at Bom Jesus.

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[2] O. A. Derby: Archivos do Museu Nacional, vol. ix, p. 72.

The present paper is chiefly concerned with the Catinga limestone, but a few words concerning the older ones are necessary in order to make clear their important relations to the later limestones of the same region.

Crystalline Limestones

The white crystalline marbles have been seen at only a few points on the São Francisco Railway at and about kilometer 434 (from Alagoinhas). Here the marble has been quarried from several pits, where it is interbedded with quartzites and associated with schists. It is quite probable that the limestones of this period are not uncommon through the region of crystalline rocks, but this is the only place at which they were seen in the State of Bahia. Similar marbles have been seen at São Caetano and near Aguas Bellas, in the State of Pernambuco,[3] and at all of these places they are associated with very old metamorphic rocks that are here referred tentatively to the pre-Cambrian.

The Salitre Limestones

The Salitre limestones and marbles are the most important rocks of the kind in the State of Bahia. They vary greatly in character, color, and thickness; they present a wide range of structural features, and they cover large areas in the northern and western portions of the State, possibly as much as 50,000 square kilometers. Toward the southern end of the Salitre Valley, especially south of Tabua, these limestones are beautiful pink and red marbles. Similar red marble was found on the plateau, 14 kilometers west of Rio Jacaré, on the road from Jacaré to America Dourada. As indicated in the table, paleontologic evidence of the age of these beds is thus far lacking, and that, too, in spite of constant vigilance and the most careful search for fossils at a large number of excellent exposures. The only fossils found thus far are small pellet-like algæ, that are quite abundant at many places, especially at Carahyba, about America Dourada and north of there in the drainage basin of the Rio Jacaré. These nodules are from less than 1 millimeter to 6 millimeters in diameter, and at many places they are so abundant as to form the mass of the rock.

Microscopic slides were made of the material, and they were submitted to Dr. Frank H. Knowlton, of Washington, who, after a very careful examination, reports concerning the rock that "it is reasonably certain

[3] Bull. Geol. Soc. Amer., vol. 13, p. 82. Amer. Jour. Sci., vol. xiii, February, 1902, p. 134.

that it is of vegetable origin, and, further, that it is most probably of an algal nature."

Specimens were also submitted to Professor A. Rothpletz, of Munich, who writes as follows:

"The one from America Dourada has a true oölitic structure. I do not know of such a structure in fresh-water deposits, but it is very common in salt-water deposits of all ages. The rock from Carahyba is also oölitic, but it is different from the American Dourada rock. It is a particular kind of oölite, which I should like to call a compound oölite. It is very common in marine limestones deposited in seas undisturbed by sand and mud. Our Wettersteinkalk, Esinokalk, etcetera, of the Trias is usually full of it, but I know it from many other places and formations."

Mr. Edward B. Wethered, of Cheltenham, England, who has given much attention to the microscopic study of oölitic limestones, writes me as follows, under date of November 29, 1909, in regard to the Carahyba rock:

"I can find no evidence that the rock is of Jurassic age. Nor can I say to what age it does belong.

"There is no evidence of life other than in the granules, which are the chief feature in the construction of the limestone. These granules I believe to be of organic origin, but I know of nothing exactly like them. The concentric growth of the granules is apparently due to low forms of life more allied to the calcareous algæ than to anything of which we at present have knowledge. This origin of the granules finds support in the quantity of carbonaceous matter left after dissolving the limestone in acid. . . . So far as I have yet been able to come to a conclusion, I am disposed to think that the carbonate of lime constituting the rock was secreted by the low forms of vegetable growth to which I have referred."

A chemical analysis was made of this oölitic limestone, with the following results:

Analysis of oölitic Limestone from Carahyba

L. R. Lenox, Analyst

Silica (SiO_2)	0.85
Iron and alumina (Fe_2O_3 and Al_2O_3)	0.29
Calcium carbonate ($CaCo_3$)	97.14
Magnesium carbonate ($MgCo_3$)	1.29
Hygroscopic water	0.08
Very small amount of hydrogen sulphide (H_2S) and organic matter	0.20
Total	99.85

The analysis shows the rock to be a very pure limestone—much purer than the average.[4]

The character of the bedding and the composition of the rocks suggest that these limestones were deposited in rather shallow waters far from a shore. The absence of false bedding suggests that the waters were not commonly affected by considerable currents, and Doctor Rothpletz's suggestion is that they are of marine rather than fresh-water origin.

The Cretaceous Limestones

The gray and cream colored limestones of the Sergipe series are only locally developed in the State of Bahia. So far as is now known, they are confined to the coastal belt in the Reconcavo, near the city of Bahia. The rocks of the Sergipe series are shown by their fossils to be of Cretaceous age[5] and of marine origin. Inasmuch as the limestones of this series are not known to occur in the region of the limsetone plains, nothing further need be said of them here.

The Catinga Limestones

The Catinga limestones are of recent date and are now in process of formation. It will be seen, however, that the agencies that are making and unmaking these rocks have long been in operation on a large scale, and it is to be expected that the oldest limestones of this kind therefore date back to the time when these agencies became active, while the newest ones are now in process of formation.

Salitre Valley

The general process of the formation of the Catinga limestones and the resulting aggradation will be understood from a brief description of their making and unmaking in the Salitre Valley.

Structurally the Salitre Valley is a great syncline. At its southern end it is bordered by the Serra de Tombador, a range formed by the outcropping of the nearly horizontal Tombador sandstones.[6] This Tombador series, although it is not everywhere visible, follows along the east side of the valley to Sargento, where it crosses the river, forming the Cachoeira do Salitre. On the west side the valley is bordered by a series of moun-

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[4] See Clark's composite analysis of 345 limestones. Bull. 330, U. S. Geological Survey, p. 27.

[5] C. A. White: Contribuiçoes á paleontologia do Brazil. Archivos do Museu Nacional VII, Rio, 1887.

[6] The geology of the Tombador range is described in Amer. Jour. Sci., vol. xxx, November, 1910, pp. 335-343.

tains that extend from the Serra da Cruz on the north to the Serra de São Mauricio, about 100 kilometers north of Morro do Chapeo. This western rim is made up of the Lavras beds and other old sediments that dip beneath the valley. Within this basin the Salitre limestones overlie the older formations, filling embayments, lapping well up over its eastern margin, and encircling the hills that rose as islands from the waters in which they were deposited. The Salitre limestone was the last great series of rocks to be deposited in the Salitre Valley. For this reason limestones are the surface rocks over most of the valley floor. The only exception worthy of mention here is a series of gravels and sands that flank the eastern base of the mountains along the west side of the valley. There should also be excepted the Catinga limestones, which are widely distributed over certain portions of the valley.

Origin of the Catinga[7] Limestones

To the character, distribution, origin, and modification of the Catinga limestones in the Salitre Valley especial attention is directed. As suggested in the table of formations in this region, the Catinga limestones are of recent origin. It is evident, also, that they are derived either directly or indirectly from the much older Salitre limestones or from any other limestone that happens to be at hand. Wherever the Catinga limestone covers any considerable area, the beds are horizontal or approximately so.

At many places temporary shallow lakes are formed during the wet season. The limy soils of the Salitre Valley are everywhere favorable for land and fresh water mollusks, and large numbers of the shells of the animals often accumulate in and about these temporary pools. On the fazenda Varzea do Sal I found the weeds growing over one of these shallow lakes literally covered with the animals that had crawled up their stems, apparently to hibernate during the dry season, while over a wide adjoining area the shells had been cemented into a compact limestone. (See plate 15, figure 1.) Such instances are common through all the flat limestone region.

Old stream beds are filled up with these recent deposits; for long distances the stream channel of the Rio Salitre has been filled until it is as flat as a floor. This is especially true of the part of the Salitre Valley above Pacuhy, or, to speak more comprehensively, it is true of those portions of the valley in which the streams are not perennial.

[7] "Catinga" is the Brazilian name of the short, scrubby forests that are characteristic of most of the semi-arid regions of the interior.

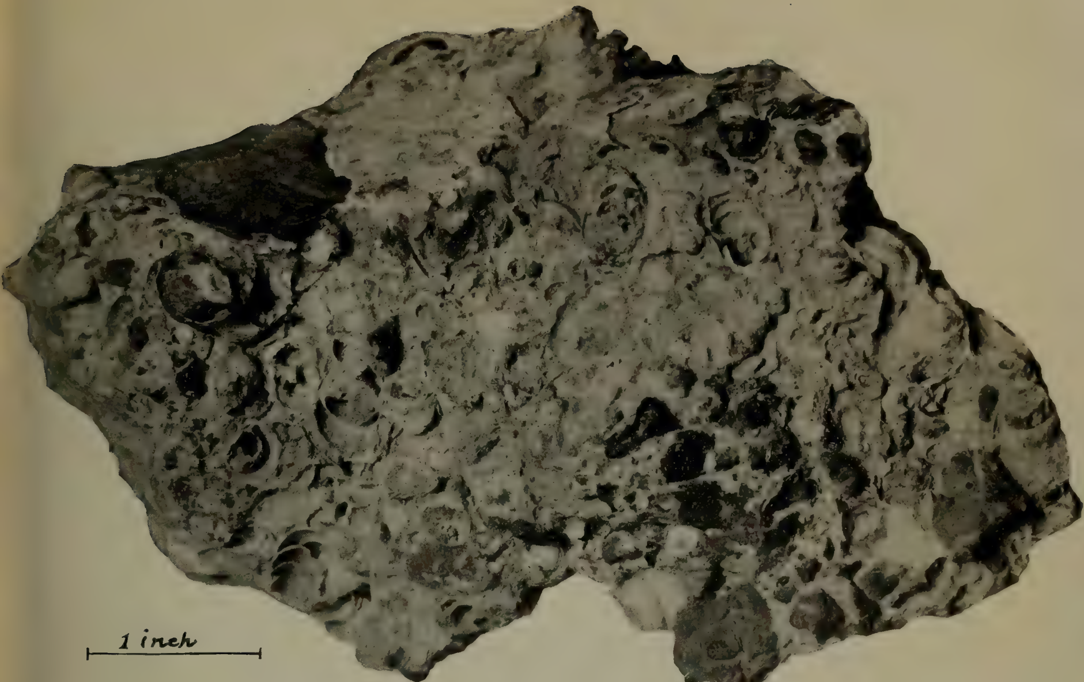

FIGURE 1.—HARD CATINGA LIMESTONE

Containing shells of land mollusks from fazenda Varzea do Sal, Salitre Valley

FIGURE 2.—TRAVERTINE BARRIER

This barrier, about 2 meters high, is across Rio Salitre at fazenda Salitre

CATINGA LIMESTONE AND TRAVERTINE BARRIER

FIGURE 1.—CHANNEL OF RIO SALITRE AT BOA VISTA

Channel is filled with recent lime deposits and bushes.

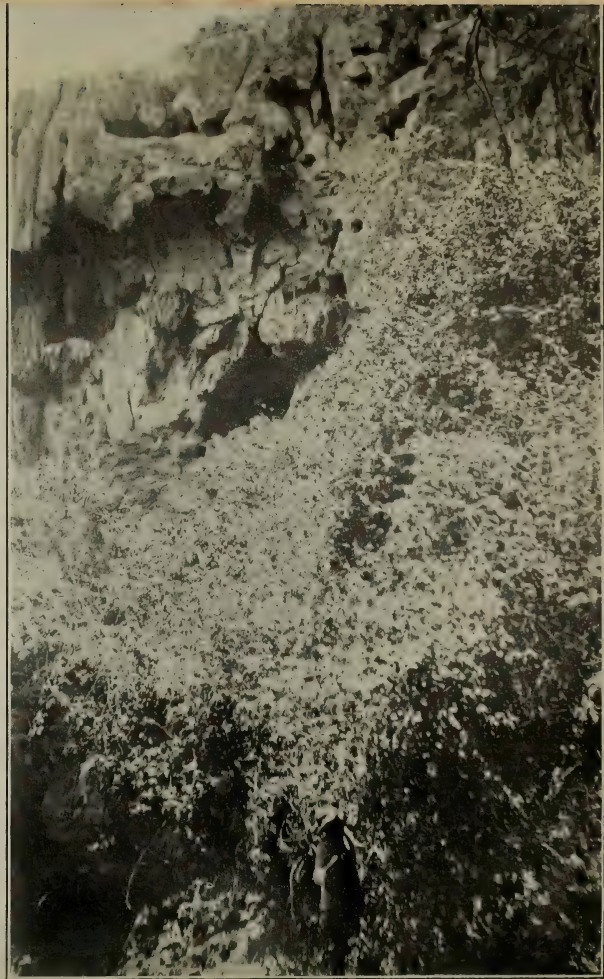

FIGURE 2.—CLIFF OF RECENT LIME ROCK

This cliff is being built across a valley that drains into Rio Salitre below mouth of Rio Ingazeira. Bluff is 16 meters high, covered with stalactites and cavernous.

CHANNEL OF RIO SALITRE AND CLIFF OF LIME ROCK

The accompanying photograph (see plate 16, figure 1), taken at Boa Vista, 75 kilometers west of Bomfim, or Villa Nova, shows the present condition of the bed of Rio Salitre at that place and in the vicinity. All the flat foreground is made of a fine, soft, cream-colored limestone, overgrown with a sparse covering of bushes and tall weeds. The banks of the stream channel are commonly steep on one side and gently sloping on the other. The entire surface of the stream channel is not so flat as this photograph suggests, but there are occasional depressions, and in the wet season these depressions contain water.

The slope of the stream bed is even and gentle, and whenever there is any sudden change of level it is marked by a natural embankment of recently formed travertine. One of these embankments is shown in the accompanying photograph. (See plate 15, figure 2.) They vary considerably in height; sometimes they are only half a meter high, but some of those seen are 4 meters high. The one shown in the accompanying photograph is a little more than 2 meters in height. The rock of which these natural embankments are made is not soft like the marly limestones filling most of the channels, but is rather hard on the upper face. They are all more or less overhanging and cavernous on the downstream side. Where the channel of the stream is not well defined, but spreads out to form arms or embayments, the floors of these embayments are flat and covered with the soft marly limestone.

The explanation of this filling up of the stream channels and the formation of these natural barriers, embankments, or dams is simple enough, in so far as the method is concerned. The waters flowing from the surrounding region of limestone are heavily charged with lime. When these waters are exposed to the sun and warmed in the shallow streams, the carbon dioxide is partly liberated and the lime is deposited over the floor of the channel. The filling usually begins at falls or cataracts and proceeds both upstream and downstream. The shallower parts fill first because of the greater exposure of the water at those places, and later the deeper pools are slowly encroached on. Any downstream slope of the stream bed that causes a rippling of the water exposes it to the air, liberates more carbon dioxide, and thus causes an increased deposition of lime on the downstream side. In time these places build up the barriers as we now have them.

The newly formed limestone, however, is by no means confined to the stream channels. Similar deposits are in process of formation over large areas of the flat portions of the limestone valleys. As so frequently happens in limestone regions, the surface of the ground is more or less pitted by sink-holes or depressions caused by underground solution and removal.

Through some of these depressions the water flows off promptly, but in most of them it stands for a time in broad shallow pools. In such places the waters bring in lime from the higher grounds, to be precipitated on exposure in the warm shallow waters or on complete evaporation. These low grounds are everywhere covered with the characteristic soft deposits of lime, showing that it is precipitated from solution.[8] The fresh deposits in these places are all soft and marly, but the old ones are as hard as any limestone ever gets to be. At many places these lime deposits, both the newer and older ones, contain plant impressions and inclose the remains of land shells. At one place on fazenda Varzea do Sal large numbers of these shells were found cemented together, forming a hard rock. So far as has been observed, the shells are forms now living on the ground. (See plate 15, figure 1.)

The process seems to explain the presence of both angular fragments and water-worn boulders of all kinds of rocks in the Catinga limestones wherever they are found.

An impressive modification of these deposits forms where the topography is favorable. Where a broad, gentle, and rather even slope carries the lime-charged waters in shallow sheets toward a channel, the lime is precipitated more rapidly along the edge of the plain, where, on account of a change to a steeper grade, the water breaks into ripples or spray. This causes the bluff to encroach steadily on the low ground, and the process must eventually lead to the low ground being entirely filled up. The accompanying photograph (plate 16, figure 2) shows one of these limestone bluffs encroaching on a narrow valley that drains into the Salitre River a few miles north of fazenda Salitre. The top of the cliff curves over like the surface of one of the travertine stream barriers. The bluff is full of caverns, produced by the irregularity of the deposit, and the roofs of the cavern are hung with stalactites. Often the travertine is deposited in masses of such shapes that they break from their own weight and form a talus slope at the base of the bluff, and this, too, in time is covered over by later deposits and is incorporated in the great limestone sheet.

Similar cavernous bluffs are found at many other places along these limestone valleys. Mr. H. E. Williams, who visited the locality at my request, sends me the following notes in regard to the one just below the falls of Rio Salitre, some 50 kilometers southwest of Joazeiro:

"At the Tocas, just below the Caxoeira, there is a beautiful limestone bluff from twenty-five to thirty meters high overhanging and full of holes and

[8] An interesting accompanying phenomenon is the distribution of recent iron deposits along the bases of the hills. This appears to be due to the more prompt precipitation of iron where the waters flow from the slopes.

caverns. The face of the bluff is covered by stalactitic projections which unite to form a good many of the caves. . . . This is the same limestone as that covering the plains south of Joazeiro."

The process as a whole is one of chemical aggradation; of leveling down of the older limestones by solution on the higher ground, and of leveling up by deposition from solution at somewhat lower elevations. It is to be noted, however, that the distance moved is not necessarily great; that the water is shallow and not concentrated in well defined streams; that the process is a slow creeping one, carried on over wide areas and for long periods.

The Climate

The climatic conditions of the region are of the utmost importance in connection with the processes of chemical aggradation. The rainfall over this catinga-covered country is confined to a few months in the year, and it is never great. The first waters soak quickly into the ground, for the surface is very dry after months of tropical sunshine and the hot winds that blow for months of the year over this region. When, at times of rain, there is more than enough water to dampen the surface of the ground, it starts to flow, but it does not go far before it all soaks into the ground. When the forest litter has once been thoroughly wet, decomposition is rapid, and the carbon dioxide formed helps attack the lime and to move it forward in the direction of the drainage. The dryness of the earth to considerable depths, however, does not permit the waters to flow away as freely as they would in regions of more evenly distributed rainfall. Where the waters are shallow the sun warms them, drives off the carbon dioxide, and the lime is precipitated, after being carried only a short distance. This precipitation may take place either in a shallow stream, in a shallow lake or pool, where the water moves in a sheet over a flat surface, or where its grade is abruptly changed at the edge of a bluff or slope of the land. Wherever the waters are completely evaporated all the lime is finally precipitated along with other minerals in solution. This process of aggradation has been in operation so long that the Salitre Valley has been affected by it wherever the limestones are the surface rocks. The rocks of the higher grounds are removed in solution, and little by little the lower grounds are built up. The less soluble parts of the limestones are commonly left behind, so that the high ground is often covered with irregular lumps and masses of flint, chalcedony, or quartz sand. Limestone hills are usually capped with quantities of such fragments, which sometimes lead one to imagine that there must be a series of siliceous rocks overlying the limestones. Thus far no such series has

been found, and we are left to conclude that the siliceous materials are only residual parts of the Salitre limestones themselves.

The Valley of Rio Jacaré

The geological history of the valley of Rio Jacaré is the same, or nearly the same, as that of the Salitre Valley. It is not necessary, therefore, to go into a detailed description of these same phenomena in that region. It may be noted that the Catinga limestones spread from the valley of the Jacaré into and over a large part of the Calmon Valley. Whether these are derived from the Salitre limestones that formerly partly encircled the Calmon Valley, or whether they have come from the Salitre limestones farther up the valley of the Jacaré, is not now known.

It is to be noted, also, in regard to the valley of the Jacaré that it is a long valley that heads in the mountains of the Chapada Velha. The immediate valley of the river is a comparatively narrow channel cut in a great plateau. The central portion of this plateau is made of closely pressed Salitre limestones, and around this and along the Jacaré is a series of sediments of later date, probably of Tertiary age. On top of the limestone plateau the Catinga limestones are forming, as already explained, filling up old river channels and extending out over the adjacent sediments. Striking examples of channels being filled up with recent lime rock are to be seen at Recife, near the divide between the Jacaré and the Verde. In one district the Catinga limestones have been replaced by silica, so that their places is taken by extensive deposits of chalcedony. These chalcedony deposits are in the Riacho Feio drainage between Gruna and Jacaré.

The Valley of the Rio Verde

The Salitre limestones of the valley of the Jacaré extend right across the watershed between that stream and the Rio Verde and westward to the base of the Serra do Gonçalves, and everywhere across the entire region the processes of solution and redeposition are in operation. The filling of old stream channels with recent limestone is noteworthy at and about fazenda Gabriel. At Recife and Gabriel, and over the wide and gently sloping watershed between the Jacaré and the Verde, not only are the stream channels choked up with deposits of lime, but many of them are now overgrown with forests, which spring not from the original channels, but from the marly deposits that fill them.

Climatic Relations

In a region as well elevated as the one under consideration we ordinarily expect to find streams deepening and widening their channels. In

the region of the Catinga limestones, on the other hand, we have stream channels now in the process of being filled up with deposits of lime rock; over their bottoms, and we have stream channels and narrow valleys being encroached on by the inbuilding of travertine banks from one or from both sides.

It is evident that there was a time not long ago when these same rivers did cut their channels; it is evident, too, that this cutting process, for some reason, has ceased, or has become so enfeebled that the actual cutting may be neglected.

The only way I have been able to account for this change in the character of the work being done by the streams is on the theory of a change in the amount of the rainfall of the region. Such a change could be brought about by a difference in the altitude of the land with reference to the sealevel.

The east coast of Brazil stood considerably higher during the Miocene than it does at the present.[9] The evidence of this Miocene elevation can not be repeated here, but it may be said that it is conclusive in regard to the time and character of the movement that the region affected included the whole coast of Bahia, Sergipe, Alagôas, Pernambuco, and probably all of northeastern Brazil, but that, so far as presented, the evidence is defective in regard to the amount of the uplift. It is clear, however, that a slight elevation, or one of a few meters only, or even of a few hundred meters, could have no considerable effect on the rainfall. The size and character of the abandoned and choked up river channels in the limestone region of the interior of Bahia suggest that the Chapada Diamentina was high enough to produce a considerably larger rainfall than we now have—quite enough to enable the streams not only to keep their channels open, but to deepen them as we should expect in an elevated region of heavy intermittent tropical rains. This period of elevation was a period of much greater precipitation and of much greater activity on the part of the streams, both in the higher and in the lower lands.

The greater rainfall of the period of elevation must have favored a ranker vegetation and a more rapid decay of vegetation, a consequent increase of carbon dioxide and an increased chemical, as well as mechanical, removal of the limestone over the entire area.

The geography of the region and especially the relations of the locality to the prevailing winds and to the ocean are factors of prime importance in this case. The winds set uniformly from the ocean toward the interior along this part of the continent,[10] and blowing from the warm ocean into

[9] J. C. Branner: The stone reefs of Brazil, etc. Bull. Mus. Comp. Zool., vol. xliv, Cambridge, 1904, pp. 127-147.

[10] E. Mouchez: Les côtes du Brésil, 2d ed. Paris, 1876; plates following p. 272.

a mountainous region the precipitation must have been proportionately greater in this part of Brazil than it would be in temperate regions.

The period of elevation and greater precipitation was followed by a period of depression, and consequently of diminished rainfall. The secondary streams were so enfeebled that they were no longer able to keep their channels clear, and these began to be choked up with lime. In those instances where the streams head on low gentle slopes the channels were quickly filled, and they have even been encroached on by the surrounding forests. With the larger secondary streams, such as the Rio Salitre, the process is still in operation, but it has already gone so far that the vegetation is now encroaching on the almost completely abandoned watercourses.

Briefly, then, the explanation of the extensive chemical aggradation going on over the limestone regions of the interior of Bahia appears to be due to a diminished rainfall in a semi-arid region, while the diminished rainfall appears to be due to the depression of the northeastern part of the continent since Miocene times.

An older Catinga Limestone

Within the immediate basin of the Rio São Francisco there are extensive deposits of limestone that differ so widely in character and distribution from the Catinga limestones of the Salitre Valley that it looks at first glance as if the explanation offered for the Salitre deposits were not applicable to the deposits along the margins of the São Francisco floodplain. Inasmuch as those older deposits have been formed under somewhat different circumstances, it is necessary to describe them in a little more detail.

The most accessible and best known of the older Catinga limestones is a series exposed along the line of the São Francisco Railway, between the stations of Angico and Piránga. This rock, however, is very hard and compact, so much so that it is much used for buildings and pavements. It was formerly supposed that this limestone was Paleozoic,[11] but later it was judged to be a fresh-water deposit "of Tertiary or possibly Quaternary age," [12] though no fossils had been found in the rocks at that time.

One of the most striking characteristics of this particular Catinga limestone is its geographic and hypsometric distribution, and its hardness and compactness as compared with the Catinga limestones of the upper Salitre Valley. The distribution is fairly evident along the line of the

[11] Theodoro F. Sampaio: Revista de Engenharia, 14 de Março de 1884, pp. 52-54.
[12] O. A. Derby: Jour. Geol., vol. xiv, Chicago, 1906, p. 380.

São Francisco Railway, where one always has the railway elevations near at hand. That particular deposit is here described in some detail because it may be taken as a type of the older deposits of the kind in the region, and because its character is suggestive of what may occur under favorable circumstances in other parts of the world.

Passing northward along the line of the railway, the Catinga limestone first appears about 8 kilometers north of Angico, in the gullies east of the railway at kilometer 391 and at an altitude of 489 meters above tide. The rock here is quite soft and marly, and forms a layer less than a foot thick. The overlying and accompanying soil has a peculiar snuff color, and beneath the limestone the rocks are granites, gneisses, and crystalline schists in place.

At kilometer 394 + 400 and 450 meters are some pits dug about 5 feet deep on the east side of the railway. These pits penetrate soft tufaceous limestones that show horizontal bedding and contain grains of quartz sand. At kilometer 394 + 560 meters a pit on the west side of the road shows the soft limestone horizontally bedded, and imbedded in the lime rock are water-worn boulders of quartzite, along with quartz sand and fragments of feldspar. In another pit on the west side of the track the limestone contains much disintegrated granite. Here was found imbedded in the soft lime rock, and about 50 centimeters below the surface of the ground, the large living land shell, *Bulimus oblongus* Mull. This was the first fossil shell found in the Catinga limestone, though many were found later.

At kilometer 395 + 10 the railway passes over the channel of Rio Mossoró. There was no water in the channel at the time when these studies were made, and the rocks exposed are all crystalline. On both sides, however, the limestone overlies the crystalline rocks. From this place northward to the top of the watershed at kilometer 400 the hard lumps of limestone thrown from the ditches beside the track show that rock is everywhere near the surface, and that it generally contains some sand and water-worn pebbles. Near the top of this grade a ditch had to be dug deeper than usual in order to drain a small lake bed (Lagoa de Mulungú), through which the railway passes, and the limestone taken from this trench is harder than that nearer the surface, while some of the water-worn boulders of quartz are as much as 15 centimeters in diameter, and smaller ones are more abundant. Some of these boulders are of granite and some are of schist. This ditch, the Vallo do Mulungú, is 1,300 meters long and extends past kilometer 399, furnishing a fairly good exposure of the limestone. The rocks are rather unevenly horizon-

tally bedded. The region seems very flat nearly to the station of Juréma, the soil is snuff colored, and the forests rather sparse catingas. At kilometer 401 + 200 the limestone seems much harder and more compact than it is farther south. Blocks a meter in diameter are exposed in the ditches up to kilometer 402. A photograph taken from the handcar at this place gives a clear idea of the character of the region and of the exposure of the Catinga limestone along this portion of the railway.

Nothing noteworthy is recorded up to kilometer 412 + 75 + 400 meters, where the cut beside the track is as much as 2 meters deep. The lumps of hard limestone thrown from the ditch have water-worn quartz boulders mixed with them.

Juréma station, at kilometer 413.5, is on the side of a shallow valley cut in crystalline rocks. An excavation opposite the station-house shows the Catinga limestone filling crevices in schists, shales, and crystalline rocks. Just north of the yard switch there is a cut 2½ meters deep, in which lumps of granite and other old rocks are mingled with the soft Catinga limestone. About Juréma station the limestone seems to be spread down over the slopes of the hills, so that it appears to have a greater thickness than it really has. The snuff-colored soil, with a thin layer of lumpy limestone beneath, continues to where the railway crosses the channel of Riacho do Tourão, about kilometer 419. Here, again, the limestone covers the flat high ground, while the stream channel at the bridge is in decomposed granites, gneisses, and schists. From where the railway again strikes the higher ground, at about kilometer 421, the limestone seems to be continuous nearly to kilometer 430, which is just south of Carnahyba station. It is on this portion of the line also that the limestone seems to reach its greatest thickness. The land slopes so gently northward that to the eye it seems as flat as a floor. The soil is of the greenish snuff color, and during the rainy season it is said to form such a pasty mass that the railway sinks into it, and material for the roadbed had to be brought from elsewhere. Over the top of it is a thin covering of quartz gravels. The vegetation is an open catinga, with very little undergrowth among the scrubby, sprawling trees.

In the vicinity of Carnahyba station (kilometer 430.87) the limestone reaches its greatest thickness, which is about 7 meters, and does not exceed 10. In the accompanying photograph (plate 17, figure 2) one man stands at the top of the limestone beds and the other at the contact of the limestone with the underlying decomposed gneiss.

Where the Rio Solidade crosses the line of the railway at Carnahyba station, the stream channel cuts deep into the crystalline rocks that underlie the limestones.

FIGURE 1.—TYPICAL EXPOSURES OF CATINGA LIMESTONE

On long tangent between Angico and Carnahyba, on the Sao Francisco Railway

FIGURE 2.—CATINGA LIMESTONE RESTING ON DECOMPOSED GNEISS

This locality is at Carnahyba station (kilometer 430), Sao Francisco Railway. One man stands at top of gneiss and the other at top of the limestone, which here is about 10 meters thick.

CATINGA LIMESTONE EXPOSURES

The lime rock is quarried at Carnahyba, and considerable lime is there burnt in crude kilns. The limestone exposed in the pits at Carnahyba is so firm and compact that the rock dresses well and even takes a good polish. This rock has been extensively used by the railway officials for station buildings, floors, platforms, etcetera. But even in these thick beds the limestone contains sand grains and occasional water-worn pebbles. A careful search was made for fossils but without success.

North of Carnahyba station the limestone seems to underlie the plateau to about kilometer 433.5. Here it seems to thin out and disappear. To the north the rocks are all schists and granites until the alluvial plains of the Rio São Francisco are reached south of Piranga.

The accompanying section, constructed from personal observations placed upon the railway profile, exhibits the structural relations and geographic distribution of the limestones between Angico and Joazeiro.

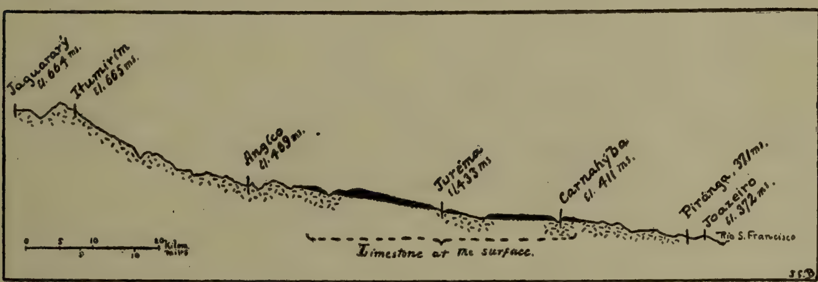

FIGURE 1.—*Profile of the Sao Francisco Railway*

From the watershed near Jaguarary to Rio Sao Francisco at Joazeiro. Reduced from profile published by Doctor Argollo in 1898. The black area is limestone. Geology by J. C. Branner.

RÉSUMÉ CONCERNING THE OLD CATINGA LIMESTONE ALONG THE RAILWAY

The characteristic features of this particular limestone deposit are as follows: it is a surface deposit following the gentle slope of the land. It rests unconformably on the old crystalline rocks of the region, penetrates the crevices in them, and enwraps boulders and residual lumps of the older rocks. Boulders are also found occasionally in any part of the beds. The older rocks rise through the limestones, forming hills and mountains. Where stream channels cross the limestone area, the underlying rocks are uncovered, but the limestone is deposited in marly layers down the slopes, especially where they are gentle. The limestone contains sand and boulders, and in the same way forms about plant and animal remains. The limestone is generally covered by a snuff-colored soil, and over this are scattered small, rusty boulders.

The old Catinga Limestone away from the Railway

Inquiries regarding the adjacent country point to the distribution of this same limestone at about the same elevation both up and down the streams crossed in this section of the railway, *except that* it does not extend up Rio do Poço Comprido above Angico. It does extend down that stream, however, and it extends both up and down the other streams, especially along Rio Solidade.

A trip made on horseback from the city of Joazeiro southwestward to the Serra do Mulato, a distance of 41 kilometers, enabled the writer to examine further this Catinga limestone in that direction. For several leagues the road is nearly parallel with the Rio São Francisco. For the first 2 or 3 kilometers it passes over the alluvial deposits of the river, after which it passes onto granites, gneisses, and schists that are cut off at the general level of the plain. Within the drainage basin of Rio Salitre, at a distance of about 38 kilometers from Joazeiro, the road passes onto the Catinga limestone. It here forms a horizontal sheet with an etched or weathered surface. It is mostly gray to cream colored and compact, like that at Carnahyba, and covers the high ground nearly to Rio Salitre,[13] a distance of about 5 kilometers. Where the immediate valley of the Rio Salitre cuts through the limestone, it is seen to be between 5 and 7 meters in thickness. At the Rio Salitre it rests immediately on greenish talcose shales that stand nearly on end. On the west side of that stream the shales continue for a short distance up the immediate valley side, but at the top of the ridge the limestones appear again and continue as a thin deposit over the floor of the plain for some 15 or 20 kilometers.

Figure 2.—*Generalized northeast-southwest Section, showing the Limestones as the surface Rocks between Joazeiro and Rio Salitre*

I did not go much farther up this lower portion of the Rio Salitre than Tapera, where it is crossed by the road from Joazeiro to Itumerim, but two of my assistants, Messrs. Crandall and Williams, went to the falls near Sargento, and they report that the Catinga limestone covers the high floodplain on both sides of Rio Salitre as far as the Caxoeira do Salitre. The section above will give an idea of the position and relations of the Catinga limestone along the road leading from Joazeiro to fazenda Itumerim.

[13] The rock at this place was noted by Spix and Martius, who speak of it as "a whitish yellow dolomite in extensive beds, very little elevated above the general level," but they say nothing further about it. Reise in Brasilien, vol. ii, p. 758.

Following this Catinga limestone to the southwest, the only thing that seems worthy of especial note is that it is cut out by all streams; that above certain levels it disappears where it enwraps the peaks of quartzite and other older rocks that rise above the plain, and that in some places water-worn boulders of quartz and quartzite are found imbedded in it that measure as much as 12 by 8 by 4 centimeters, and with these are many smaller boulders. No fossils were found in these exposures, but the rock looks promising for fossils.

Inquiry regarding the limestone at or about this same elevation over the river plain of the São Francisco brings out the fact that the horizontality of the deposit, its thickness, its position on the low watersheds, and its absence from the immediate stream channels are pretty constant characteristics over the ancient floodplain of this section of the river.

It is reported to occur over the low land along the Rio São Francisco as far up as Bom Jesus da Lapa, and along the Rio Corrente and Carinhanha, on the west side of the São Francisco. Below Joazeiro it is reported as far east as the valley of the Rio Patamuté.

In the region about Joazeiro the Catinga limestone, so far as now known, is confined to an elevation below 500 meters above tide, and most of it is above 400 meters. Data are not at hand to show its elevation higher up the São Francisco, but in view of the conditions under which it was deposited it is expected that it will maintain a rather even vertical range between 40 and 125 meters above the ordinary stages of that stream.

Origin of the Catinga Limestone of the São Francisco Floodplain

In connection with the theory of the origin of this older Catinga limestone it should be mentioned that when the question of its origin first presented itself the theory of its having formed in a shallow lake was entertained. In the presence of the facts gathered this theory does not seem to be tenable; nor does the explanation of the origin of the Catinga limestone in such areas as the Salitre, the Jacaré, and the Rio Verde valleys seem to explain the extensive deposits on the high margins of the immediate valley of the Rio São Francisco. The process, however, is believed to be only a modification of the one now in operation in the lateral valleys. The distribution of these older beds show that they were deposited in the shallow waters of the São Francisco itself when those waters spread over the area in which these rocks are now found. I believe they belong to the period of heavy Miocene rainfall, when the region stood considerably higher than it does at present. During that period the floods of the Rio São Francisco were greater than they are now, and

when they spread over this flat region the lime was precipitated wherever the shallow waters were warmed sufficiently. In periods of floods the water spreads out over enormous areas, and when these floods subside the mere draining off of the shallow waters requires a long time, for its movement is greatly retarded by vegetation and by ground friction. The lime is precipitated more promptly in the shallower waters—that is, on the higher portions of the flooded areas—owing both to the warming of the waters and to their disturbance.

Two additional bits of evidence of the former greater volume of the São Francisco deserve mention. One is the distribution of the river gravels over the ancient floodplain far beyond the reach of the highest waters of recent times; the other is the water-worn condition of the bedrocks.

On the fazenda Itumerim, some 30 kilometers south of Rio São Francisco, and within 200 meters of the base of the Serra do Mulato, are some bosslike outcrops of compact and very hard, fine grained granites that rise 2 or 3 meters above the general level of the plain. These bosses are somewhat exfoliated from exposure to the sun, but at many places over their surface, and especially near their bases, are well preserved remnants of water wearing. These worn surfaces are not pits or depressions, such as are often made by aborigines in grinding food, but they are uneven and rounded, pecked and polished like the channel of a stream cut in the solid rock. These bosses, moreover, stand on an open plain, where they are quite out of the reach of any possible wearing by local streams. From these bosses all the way to the Rio São Francisco the surface of the plain is strewn with water-worn and subangular boulders, here more abundant and there thinning out until they almost entirely disappear.

The plain between the river and the base of the Serra do Mulato is not alluvial, but a nearly flat floor of granites and very old crystalline rocks, with here and there steep-sided hills of quartzite. The evidence of a broad, water-worn and abandoned floodplain might, if taken alone, be regarded as evidence of the later lowering of its channel by the river. And some lowering has taken place, but the abandoned floodplain, considered in connection with the distribution of the limestones, seems rather to be a part of the history of the drainage when the entire region had a much larger rainfall.

Age of the Catinga Limestone

From what has been given in regard to the method of formation and distribution of the Catinga limestone, it is evident that it has been and is being formed by a process that has long been in operation and is in operation today. I am therefore unable from field observations alone to refer the rock to any particular geologic horizon.

The fossils found in the Catinga limestone seem to bear out this theory of its age. So far as these fossils have been studied, they all belong to forms now living. A few specimens found at Varzea do Sal, in the Salitre Valley, were submitted to Dr. Wm. H. Dall, of the Smithsonian Institution, who under date of November 8, 1909, writes as follows:

"I have carefully examined the specimen you sent and find the land shells it contains comprise at least two and possibly more species of *Bulimulus* of the subgenus *Anctus*, still characteristic of the region. This subgenus is at least as old as the middle Oligocene, but the species of that age, so far as I have seen them, are small. Yours are much larger and probably not so old. I should suspect them to be in a general way Miocene or Pliocene, but of course there is no way of arriving at certainty from the fossils alone."

At many places one finds the living shells in the process of being imbedded in the limestone now forming.

In speaking of the older Catinga limestones, I have ventured to refer them tentatively to the Miocene. I fully realize that such a reference is risky from a paleontologic point of view; but, in the absence of diagnostic fossils, nothing better can be done at present. The reason for referring the rocks to any horizon at all lies in their stratigraphic relations to the rocks about them in the evidence of a Miocene uplift of the region and of a greater rainfall during that period.

Résumé of Conclusions

In the secondary valleys of the semi-arid limestone regions of the interior of Bahia chemical aggradation is in progress on a large scale.

This aggradation consists in the removal in solution of the older limestones of the higher grounds and their deposition over the plains and in the stream channels. These deposits bury up and enwrap anything that happens to lie on the valley floor or in the channels of the secondary streams, so that locally they contain boulders and rock fragments of many kinds and plant and animal remains. Land and fresh-water shells are especially abundant in these newly formed rocks in some localities.

Over large areas the channels of the secondary streams are already completely filled with these lime deposits and vegetation has encroached on them until they are now covered by the ordinary forest growths. Only the large perennial streams, like the São Francisco itself, are able to keep their channels open and free from these lime deposits.

Over broad flat surfaces of the side valleys the rain waters move the lime forward year after year, taking it up on the somewhat higher grounds and depositing it on the somewhat lower lands. In some places the lime deposits form at and down over the faces of bluffs, which are thus

built inward until the stream channels are obliterated. In some places the ingrowing valley margins have inclosed extensive caverns.

With age the deposits change from soft marly beds to hard and compact limestones.

In the immediate valley of the Rio São Francisco there are extensive deposits of a similar nature, but apparently older than those forming in the lateral valleys at present.

From the occurrence of these older deposits of the main valley and the method of their formation it seems probable that the Catinga limestone will be found in all of those parts of the arid and semi-arid portions of Brazil where there are older limestones from which they may be derived.

They are not to be expected in those parts of the country where rainfall is sufficient to keep the stream channels open, but in regions of strong drainage one would expect a Catinga limestone to be deposited only over the higher portions of the floodplains.

The formation of the Catinga limestones and their peculiar distribution are believed to be due to climatic conditions in combination with the distribution of extensive older limestone deposits from which the secondary beds have been derived. The conditions referred to relate to the variation in the amount and distribution of the rainfall in the region.

A former study of the geography and geology of the coast of northeastern Brazil has led the author to the conclusion that during Miocene Tertiary times the region stood at a much greater elevation than it does at present, and that this elevation was followed by a depression during the Pliocene. It is therefore inferred that precipitation throughout northeastern Brazil, where the winds set constantly inland, was considerably greater during the period of uplift, and that the greater activity of the streams of that period are attributable indirectly to this elevation. The present semi-arid condition, the cessation or great diminution of the mechanical work of streams, and the choking of their channels and the extensive deposits of Catinga limestone in the secondary valleys are all believed to have been brought about by the Pliocene depression and the consequent decrease of precipitation. These conditions—that is, the former elevation and later depression of the land—have affected a wide area in northeastern Brazil, especially in the interior, including the States of Bahia, Sergipe, Alagôas, Pernambuco, Parahyba, Rio Grande do Norte, Ceará, and possibly still others.[14]

I have no doubt that considerable local differences in precipitation are so produced, but they do not seem to be capable of bringing about the widespread changes that have affected northeastern Brazil as a whole.

[14] Dr. E. L. Voss attributes the aridity of Ceará to the surrounding mountains. See "Die Niederschagsverhältnisse von Sudamerika." Ergänzungsheft, No. 157 zu Petermann's Mitteilungen, Gotha, 1907. Also Geogr. Jour., July, 1908, p. 77.

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AFTONIAN MAMMALIAN FAUNA II [1]

BY SAMUEL CALVIN

(Presented before the Society December 29, 1910)

CONTENTS

INTRODUCTION

Since the preparation of the paper on the "Aftonian mammalian fauna," which was published in October, 1909,[2] a large amount of new information and new material has been received. Our knowledge of the surprising volume and geographic distribution of the Aftonian gravels has been greatly extended during the past two seasons by the field work of Shimek, who has devoted much time to the study of the problem and has noted and recorded the occurrence of true Aftonian deposits at short intervals over a wide belt, reaching from Sioux Falls, South Dakota, to Rockport, in northwestern Missouri. There are reasons for believing that the area studied includes but a mere fraction of that in which fossil-bearing Aftonian beds are distributed. Aftonian deposits are found on both sides of the Big Sioux and Missouri rivers; they are known in Muscatine County and a number of other localities on the Mississippi, and there are intermediate points where they are well developed.

[1] Manuscript received by the Secretary of the Society January 30, 1911.
[2] Bull. Geological Society of America, vol. 20, Oct., 1909, pp. 341-356.

Besides the Aftonian, there are two other horizons, conspicuously gravel bearing, in the Pleistocene deposits of Iowa. One is represented by the extensive beds of Buchanan gravels, which were evidently laid down at the time of melting of the Kansan ice and are super-Kansan in stratigraphic position; the other—much younger—is related to the disappearance of the Des Moines ice-lobe of the Wisconsin. There is a third post-Aftonian horizon—one which furnishes beds of clean quartz sand with practically no gravel—showing deposits made by floods from melting ice, related to the waning of the glaciers of the Iowan stage. Gravels of the later stages are not always readily discriminated unless the stratigraphic positions are unmistakably indicated, and in the field work of the past two years nothing that did not show clearly its relation to the Kansan, or the Nebraskan, or to both, has been set down as Aftonian. In accordance with this rule the gravel pits at Denison are to be transferred, temporarily at least, to the doubtful list. Though they are located in the valley of the Boyer River—the stream on which the noted pits at Logan and Missouri Valley occur—and though, according to Shimek's determinations, so far as the scant contained mollusks are concerned, they are faunally the same as the beds farther down the stream, and though structurally and otherwise they appear to be identical with deposits that are certainly Aftonian, the relation to definitely determined drift sheets is not clear. The lower contact of the gravels is not seen; their upper surface is overlain by loess, which shows an older and a newer phase, but there is no till-sheet in sight either above or below to fix the exact horizon. Judgment relative to the age of the Denison pits should, therefore, be suspended until their status has been established. The few mammalian fossils collected from the Denison pits should be checked out of the Aftonian fauna, except so far as they have been or may be confirmed by collections from beds of demonstrated age. The standing of *Elephas primigenius* and the great stag, *Cervalces,* will be affected, at least temporarily, for these have not yet been found in other localities in beds of undoubted Aftonian.

Fossilization and Mode of Preservation

As the collections increase in number of specimens, and as they represent a wider geographic range, it is seen that, with the exception of the few collected from silt beds, all the true Aftonian fossils agree in a remarkable way in the amount of change or fossilization that the bones and teeth have undergone. To a very noticeable and large extent those from the arenaceous beds have all been changed by the infiltration of silica. They are decidedly stony and hard and heavy, and they differ in

marked degree from portions of proboscidean and ungulate skeletons which have been received from apparently younger gravels at Le Mars, Rock Rapids, and a few other points in northwestern Iowa. In many cases the Aftonian sand and gravel are cemented into a hard conglomerate around the fossils, forming an indurated siliceous shell, ranging up to half an inch in thickness, and adhering more or less firmly to the inclosed skeletal remains. The deposition of silica, which altered the composition and hardness of the fossil bones and teeth, affected the inclosing matrix of sand and gravel for a short distance outside the surface of contact.

In a majority of the gravel pits the fossils are stained more or less with metallic oxides. Ferric oxide is one of the products of chemical changes caused by the weathering of pebbles carrying iron-bearing minerals, and there are few Aftonian exposures that do not show streaks and pockets of manganese dioxide. The bones and teeth where these oxides occur are colored in various shades, ranging from light to very dark brown. Where clean quartz sand predominates, the fossils, while becoming silicified as completely as in the other cases, retain their original whitish color. The Elliott pit at Turin contains largely coarse, sharp quartz sand, and stands almost alone in furnishing specimens conspicuously light in color, free from metallic stain. The same fauna, however, occurs in all the pits of true Aftonian—the same horses, proboscideans, ground sloths, and camels, and the skeletal remains—whether from Rockport, Missouri; Sioux Falls, South Dakota, or from points between—all show the same mode of preservation, all, especially from the siliceous phase of the formation, are fossilized in about the same way.

Carnivores

One of the remarkable features of the Aftonian fauna, so far as the very meager knowledge of it has yet progressed, is the practical absence of Carnivores. At the time the first paper was written no remains of carnivorous mammals had been received from undoubted Aftonian deposits, and the work of the past two years has brought to light only one specimen to represent the flesh eaters, the right ramus of a large bear (plate 18). The teeth remaining in the jaw are the canine, fourth premolar, and first molar, and all are very much worn. The second and third molars have fallen out since the death of the individual, possibly since it was collected by the workmen in the sand pit. The canine is very large, elliptical in cross-section, and shows evidence of great wear on the tip and anterior edge, and this wear has reduced it to a mere blunt stump of what it was when showing its full length. Evidently the animal had reached a ripe old age. The dimensions are: greatest length of ramus,

200 millimeters (about 7⅞ inches); height of coronoid, 102 millimeters (about 4 inches); antero-posterior diameter of crown of canine at base, 23 millimeters; transverse diameter of same, 13 millimeters.

Ungulates

HORSES

A great proportion of the new material simply duplicates and verifies that previously known. In the collections horses still predominate, so far as number of teeth and recognizable parts of the bony skeleton are concerned. The majority of the teeth belong to the large species, which in the first paper was identified with Gidley's *Equus scotti;* but at least one large molar from the Turin pit agrees with number 117, which was noted in paper I, page 350, as having dimensions which might justify its reference to *Equus pacificus.* Some of the equine phalanges and metatarsals are certainly larger than those of the average domestic horse, and these indicate the possibility at least of an Aftonian species outranking *Equus scotti* in size. On the other hand, there are smaller molars of the *E. complicatus* type, and two inferior grinders from Aftonian beds exposed in a cut on the line of the Illinois Central Railroad near Sioux Falls, South Dakota, are notably smaller than any of the corresponding teeth from other localities. The specific relations of these last mentioned teeth must await larger collections and fuller information. Two splint bones, one from Turin and one from Missouri Valley, are parts of equine skeletons not previously collected. Though not deciding with certainty when Pleistocene horses became extinct, it may be noted that in Iowa no equine remains have yet been found in deposits younger than the Aftonian.

On page 138 of the paper on the "Present phase of the Pleistocene problem in Iowa"[3] there is brief notice of a small, slender limbed horse, which is indicated by a few fossils collected from the Aftonian beds near Afton Junction and Thayer (plate 19, figures 1-4). The fossils referred to include an astragalus, the larger part of a metatarsal, a proximal phalanx, and one or two unerupted teeth, from which no effort was made to determine the enamel pattern. Inasmuch as no other mammalian remains are known from the Thayer and Afton Junction pits, it was assumed that these fossils might possibly be remains of some preglacial animal accidentally included in the interglacial gravels, and so reference to them is omitted from the paper published later on the Aftonian mammalian fauna. Taking into account the history and genesis of the gravels, the successive stages and conditions through which the bones must have passed

[3] Bull. Geological Society of America, vol. 20, March, 1909, pp. 133-152.

if the assumption is true, the certainty of wear and the equal certainty that the parts of the individual skeleton would have been widely separated instead of occurring near together, the assumption has always seemed highly improbable, but the doubt was sufficient to turn the scale in favor of conservatism. Lately a very perfect upper molar of a horse, corresponding in size to that indicated by the fossils from Afton Junction, has been found in true Aftonian beds, associated with the typical Aftonian fauna, the mammalian remains showing the usual Aftonian phase of fossilization. The molar (plate 19, figures 5-7) belong to the genus *Hipparion,* and the enamel pattern is somewhat like that of *Hipparion gratum* Leidy. The specific determination is, however, left for the present unsettled. The tooth was taken from the Whitham gravel pit in section 22, township 64 north, range 41 west, south of Rockport, Missouri. A considerable amount of material from this pit has been scattered and lost; in the small collection in hand the true horse, *Equus,* is represented by one metatarsal, four lower molars, and one worn upper molar. This last measures 33 millimeters in transverse diameter, agreeing in size and in other characters with the teeth, which have been referred to *Equus scotti* Gidley. A large camel is represented by one premolar; there is a grinder of *Elephas columbi,* the common Aftonian elephant, and there is a part of a large tusk. The Hipparion molar is fresh and unabraded, and, while not making it absolutely sure, it increases the probability that the small equine fossils from the Afton Junction-Thayer region belong to a member of the true Aftonian mammalian fauna. *Hipparion venustum* Leidy, originally described as *Hippotherium venustum,*[4] is credited to the post-Pliocene, and it was found associated with Equus, Elephas, Mastodon, Castoroides, Mylodon, and other characteristic Pleistocene types.

DEER

A metacarpal from Turin, a part of the lower jaw with molars from the Cox pit, and some other less satisfactory fragments of the cervine skeleton from different localities indicate an animal closely related in size and structure to the modern Virginia deer.

CAMELS

The new collections contain foot bones and teeth of mammals belonging to the Camelidæ. There are toe bones corresponding in size to that illustrated by figure 1, plate 21, of the first paper; but there is one proximal phalanx from Aftonian gravel at Hinton station, near Council Bluffs, which is much stouter and heavier than that represented in the

[4] Description of vertebrate fossils, by Joseph Leidy, in Holmes' post-Pliocene fossils of South Carolina. Charleston, 1860, p. 105, pl. xvi, figs. 32, 32*a*, 33, 33*a*.

figure referred to. In length it is about the same, but the transverse diameter at the proximal end is 56 millimeters instead of 36, and the smallest diameter of the shaft is 31 millimeters instead of 20 (plate 19, figure 8). A second phalanx from the Turin pit (plate 19, figure 9) matches the larger one in size and may belong to the same species. The Turin phalanx is unsymmetrical and is obviously one of a pair of similar bones. A large premolar from the Whitham pit, near Rockport, Missouri (plate 19, figure 10), may belong here, and a number of bones too large for even the biggest horse or stag may represent this species. Among these are the distal end of a humerus from Hinton, a dorsal vertebra, and two large calcanea from Missouri Valley and a fragment of the scapula, carrying the large glenoid fossa, from Turin.

Proboscideans

ELEPHAS

The southern mammoth, *Elephas columbi,* is represented by characteristic molars from Logan, Turin, and Hinton in Iowa, and from Rockport, Missouri. This is the most common of the Aftonian elephants. The collections from Hinton contain a small molar, probably the fourth of the series, which shows the thick folds of *Elephas imperator.* Four teeth of this imperial type are now known from Aftonian beds—one from Pisgah, Iowa, one from near Mapleton, Iowa, and this from Hinton Station, besides a lower jaw from the Cox pit, near Missouri Valley, Iowa.

Two elephant teeth have recently been taken from the gravel beds at Denison, but, as noted above, the stratigraphic position of the Denison gravels has not been determined with entire certainty.* One of the molars (plate 20) is the last of the upper series on the right side, evidently belonging to the species *Elephas primigenius,* and adhering to it is a part of the molar bone. The dimensions of this superb tooth are: length of grinding surface, 10½ inches; width, 4½ inches; depth at right angles to grinding surface, including the massive posterior fang, 10⅞ inches; greatest length parallel to grinding surface, 13 inches. The tooth is worn through to the fangs at the anterior end. Posteriorly there remains a large body of serviceable tooth, and with continued wear laminæ that had not been used would have been added to the grinding surface. The vertical sides and posterior edge of the grinder are covered with a coat of

* Note.—These teeth and some of the earlier mammalian remains were taken from a pit southwest of that discussed in previous papers. The stratigraphic position of the beds exposed in this pit is even more doubtful than Professor Calvin considered it, for they here form a river terrace without overlying loess or drift, and no underlying drift was found. The loess-covered beds discussed in the earlier papers yielded few mammalian remains. The terrace beds show some evidence of later redeposition.

B. Shimek.

cementum four to five millimeters in thickness. In the anterior two-thirds of the grinding surface the enamel is looped back and forth from the outer edges to the middle in the manner represented in figure 6, plate 148, of Owen's Odontography, a figure described as showing "the more normal form and structure" of the molars of *Elephas primigenius.* This arrangement of the enamel seems, however, to be rather unusual. One other tooth in our collections, which was taken from gravels near West Union, Iowa, in 1875, has the enamel disposed in this way. Of the many molars of *Elephas primigenius,* figured in part II of A. Leith Adams' "Monograph on British fossil elephants," there is just one—figure 1, plate XIV—that shows this feature, and in this case the looping is limited to the anterior third of the grinding surface. The tooth figured by Adams, like the Denison tooth, is the "right upper last true molar," but his must have belonged to an animal smaller than the Iowa form.

At the meeting of the American Association for the Advancement of Science, in Dubuque, in 1872, the writer had the privilege of seeing the tooth, which Foster regarded as the type of a new species of fossil elephant, *Elephas indianapolis,* and of hearing his description of it, and one at least of the distinguishing characters of the supposed new species was the looping of the enamel from the middle of the grinding surface to the sides, instead of the usual arrangement of this tissue in elongated ellipses surrounding plates of dentine.[5] In the bibliography and catalogue of the fossil vertebrata of North America, by Hay, Bulletin of the United States Geological Survey, No. 179, page 714, the tooth described by Foster is assumed to be one of the forms of molars of *Elephas primigenius.*

The extent to which silicification has progressed in the large tooth and adhering bone from Denison is not so great as in the fossils certainly known to be Aftonian. For the present the age may be left undecided. It is possible, however, that *Elephas primigenius* belongs to a stage more recent than the Aftonian, and that it was not contemporaneous with the *Equus* and *Elephas imperator* fauna.

MASTODON

The new collections contain a number of teeth of *Mastodon americanus,* but the most important addition to the mastodon series is a massive lower jaw from Missouri Valley (plates 21 and 22). The ascending branch is

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[5] *Elephas indianapolis,* a new species of fossil elephant, by J. W. Foster. Proceedings of the American Association for the Advancement of Science, twenty-first meeting, held at Dubuque, August, 1872, p. 259. The title only is printed in the Proceedings. After the reading of the paper, and at the suggestion of some of the naturalists present, Foster proposed to change the name to *Elephas mississippiensis,* and under this designation there is a short reference to the paper and the proposed species in *Nature,* vol. vi, p. 443.

missing on the right side, but the left ramus is complete. The dimensions are: length, 32⅝ inches; height of coronoid, 16¾ inches; height of articulating condyle, 16⅛ inches. There are sockets for mandibular tusks, and the indications are that these were about equally developed on the right and left sides. The last molars are the only ones remaining, and they are worn to the roots. None of the enamel of the transverse ridges is left, but the thick enamel which covered the outside of the crown forms a continuous ridge around the deeply concave grinding surface. The cup-like feature of the molars is due to rapid wear of the softer dentine in the interior of the tooth, the outside being protected by the rim of harder tissue.

The deeply concave form of grinding surface, developed by protracted wear, seems to have had serious disadvantages. Both teeth are split vertically, as seen in plate 22, and there are indications that the splitting occurred while they were in use, some time before the death of the animal. The sides of the fissures are stained in precisely the same way as the surface of the dentine in the bottom of the concavity which characterized the grinding surface, and the angles have been rounded off by evident use since the injury occurred. There is a later, probably post-mortem, fracture of the right molar which shows a very different appearance. There is evidence of abrasion and polish on the inner surface of the wall surrounding the concave grinding surface, which indicates that the opposing teeth of the upper jaw operated in a way to exert a tremendous wedging or spreading force, and the strain, repeated every time the ponderous jaws were closed, overcame the cohesion of the greatly weakened molars. Only a small amount of the original main body of the teeth remained below the level of the concave grinding surface.

A last molar of *Mastodon mirificus* was received from a resident of Missouri Valley, but the specimen had passed through several hands before it came into his possession, and he could give no definite account of where the tooth came from or under what circumstances it had been found. In general appearance and degree of fossilization this specimen agrees with those from the Aftonian. Fossil-bearing Aftonian occurs near Missouri Valley; beyond these statements nothing more definite can be said at present concerning the locality and geological position to which this new molar should be referred. The tooth is much less worn than that illustrated in plate 27, opposite page 355, of the preceding paper.

OTHER PROBOSCIDEAN REMAINS

Of the proboscidean remains that can not readily be referred to either the elephant or the mastodon, a few only deserve notice. From the Cox pit there are two well preserved dorsal vertebræ and a large fragment

embracing the occipital and basal parts of the cranium, including the foramen magnum. These all show the usual stain and the usual Aftonian phase of fossilization.

In addition to the Aftonian specimens noted above, there are proboscidean bones from gravels belonging possibly to other horizons. Within the year there has been received an imperfect ilium, but with the acetabulum complete, from Le Mars; the lower end of a scapula, with glenoid fossa and part of the acromion spine, from Lake View, and a large, fairly perfect atlas comes from gravels at Rock Rapids. These are not silicified to the same extent as fossils from the Aftonian, and it is probable they represent faunas of later stages. About 1876 a complete skeleton of *Mastodon americanus* was found near Adel, in Dallas County, imbedded in peat that partly filled a "kettle" in the surface of the Wisconsin drift. This fact may be cited as part of Iowa's contribution to the great volume of evidence that the mastodon was here in post-Glacial time, and may have been present during each of the post-Aftonian interglacial stages.

RODENTS

The great Pleistocene beaver, *Castoroides,* is represented by a part of an incisor from the Elliott pit at Turin, Iowa, and a molar from the Collins pit, near Sioux Falls, South Dakota. In 1907 a nearly perfect incisor (plate 23) was found in sand pumped from the Nishnabotna River, near Oakland, Iowa. There is fairly clear evidence that the sand of the Nishnabotna Valley is Aftonian. It occurs in a region that was not reached by the streams which deposited the younger sands and gravels.

EDENTATES

Additions to our knowledge of the Aftonian ground sloths are limited to a few parts of the skeleton of *Megalonyx.* There is a patella from the Anderson pit at Sioux City, a right radius (plate 24) from the Elliott pit at Turin, and a right tibia from the Cox pit at Missouri Valley. The radius is complete and unabraded, and, except that it is a trifle smaller, it agrees almost perfectly with Leidy's figures and descriptions of the radius of *Megalonyx jeffersoni.*[6] The ulnar articular facet is more nearly circular than in the specimen described by Leidy, if judgment may be based on the descriptive term "demi-circular," which is applied to this feature of the bone in the text. The bicipital tuberosity is somewhat more prominent in ours than in Leidy's specimen, and the rugosities of the anterior surface are more pronounced. In all essential particulars, however, the cor-

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[6] A memoir on the extinct sloth tribe of North America, by Joseph Leidy, M. D., p. 27 et seq. Illustrations of the left radius are given on plate ix, figure 5, and plate x, figure 1.

respondence is perfect. Length of the Turin radius, $16\frac{5}{8}$ inches; greatest width, which is near the distal end, $3\frac{1}{2}$ inches. The tibia from Missouri Valley is not perfect. The shaft is complete, and parts of the articulating surfaces at each end remain, but more or less of the great expansions at both extremities have been broken off. The parts left agree with the descriptions and dimensions of the tibia of *Megalonyx jeffersoni* given by Leidy. The patella and ungual phalanx from Sioux City agree likewise with the corresponding parts of the species named; there is little doubt that one of the Aftonian ground sloths is the *Megalonyx jeffersoni*.

Description of Plates

Plate 18.—Aftonian Fossils

Right Half of lower Jaw of Bear.

From Aftonian gravels, Cox pit, Missouri Valley, Iowa. About seven-eighths natural size.

Plate 19.—Aftonian Fossils

Figures 1-4.—*Foot Bones and superior unerupted Molar of small Horse.*
From the gravels near Thayer.

Figures 5-7.—*Outer, lateral and crown Views of upper Molar of Hipparion.*
From Rockport, Missouri.

Figure 8.—*Proximal Phalanx of Camel.*
From Hinton Station, Iowa.

Figure 9.—*Second Phalanx of probably the same Species as 8.*
From Turin, Iowa.

Figure 10.—*Premolar of Camel.*
From Rockport, Missouri. (All figures natural size.)

Plate 20.—Aftonian Fossils

Grinding Surface of last right upper Molar of Elephas primigenius.

From Gravels of uncertain age at Denison, Iowa. About nine-fourteenths natural size.

Plate 21.—Aftonian Fossils

Left Ramus of Mastodon americanus.

From Aftonian beds, Cox pit, Missouri Valley, Iowa. Slightly more than one-fifth natural size.

Plate 22.—Aftonian Fossils

Upper View of imperfect Mandible of the American Mastodon.

Showing the much worn and deeply concave last molars and the wide fissure in each molar due to splitting while the teeth were still in use.

Plate 23.—Aftonian Fossils

Inner and outer Views of lower Incisor of Castoroides ohioensis.

From sands, probably Aftonian, near Oakland, Iowa. Natural size.

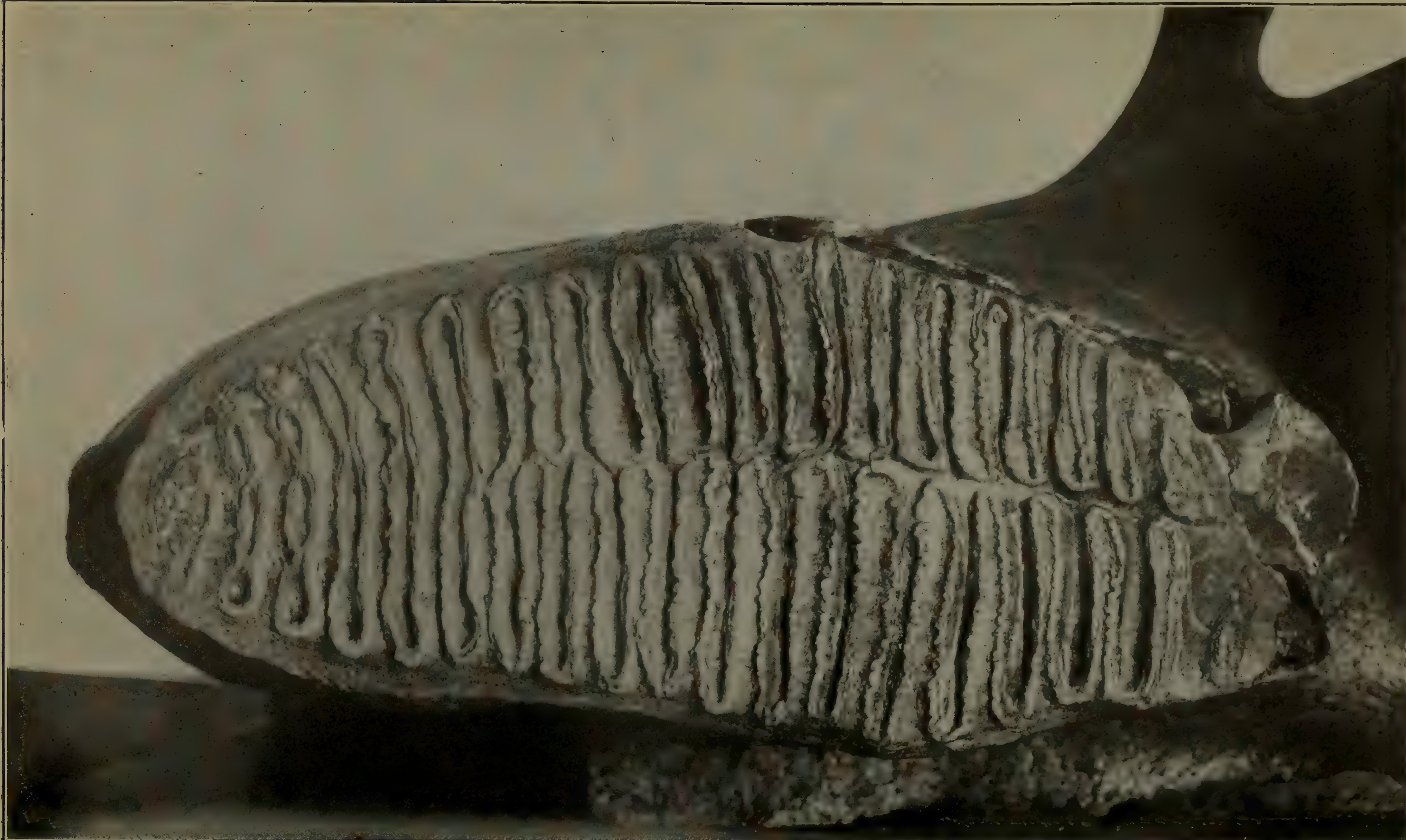
Plate 24.—Aftonian Fossils

Ulnar and anterior Views of right Radius of Megalonyx jeffersoni.

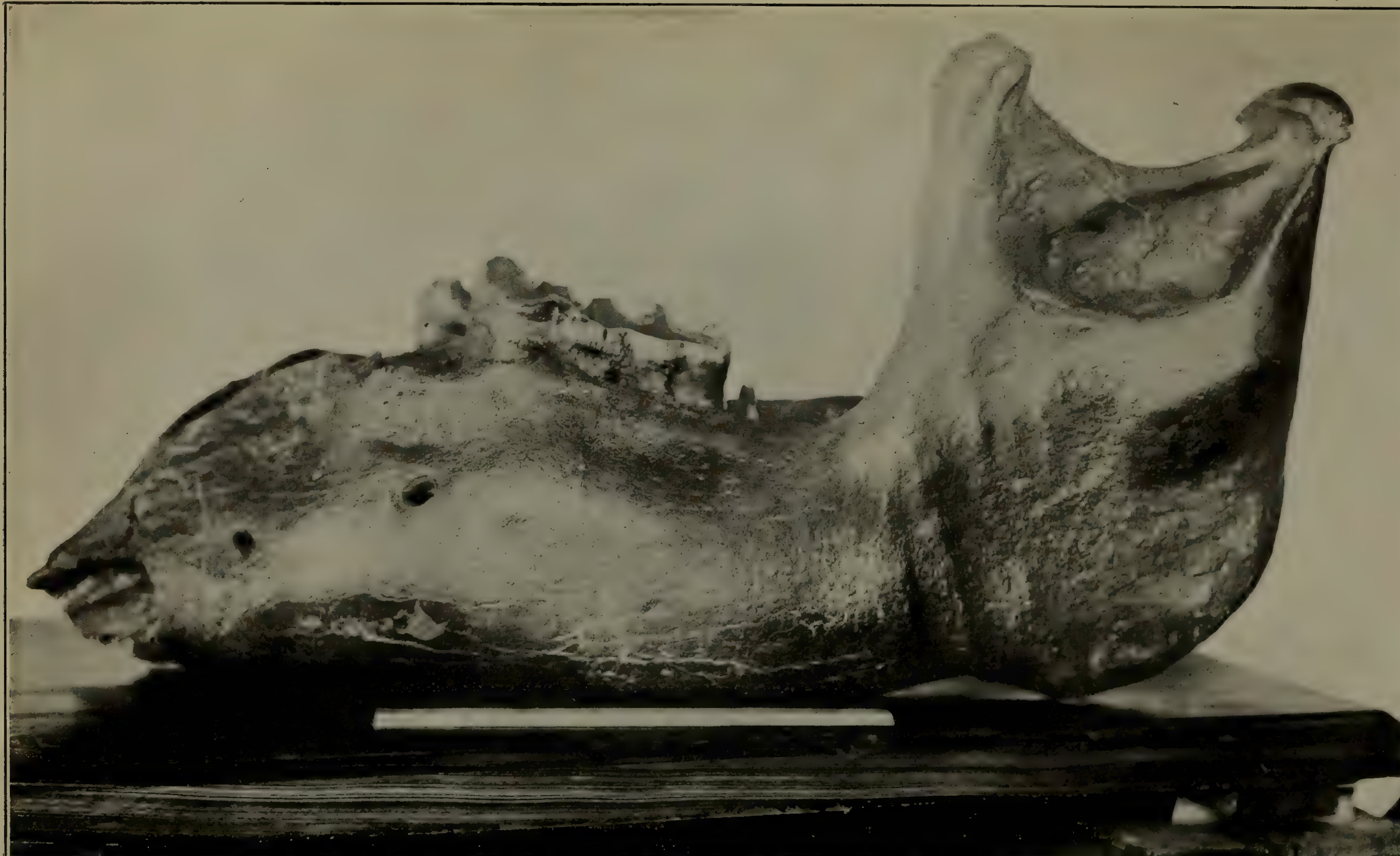
From Aftonian sands, Elliott pit, Turin, Iowa. About seven-sixteenths natural size.

AFTONIAN FOSSILS

AFTONIAN FOSSILS



AFTONIAN FOSSILS



AFTONIAN FOSSILS

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

CONFERENCE ON THE FAUNAL CRITERIA IN PALEOZOIC PALEOGEOGRAPHY

R. S. BASSLER, *Secretary*

CONTENTS

INTRODUCTION

The Council of the Paleontological Society voted that at the Second Annual Meeting, held at Pittsburgh, that the greater part of one day should be given to a conference on the faunal criteria of use in paleogeography for the discerning at what probable depth the Paleozoic sediments were deposited, the shorelines of such deposits, the temperature of the water, the factors indicating faunal provinces, and the effect of currents on the life assemblages. To this end the President of the Society, Prof. Charles Schuchert, secured the cooperation of a number of paleontologists, each one being well versed in the topic selected, and December 29, 1910, was selected for the presentation of papers. As the time limit set for each paper was short, the participants could not always give the desired detail on which their conclusions were based.

NATURE OF TERTIARY AND MODERN MARINE FAUNAL BARRIERS AND CURRENTS[1]

BY WILLIAM H. DALL

Were the earth evenly covered with water of a uniform depth and density, or the dry land confined to circular zones of which the center coincided with the axis of the earth's rotation—in other words, with the poles—it would be mathematically possible to compute the extent and course of the marine currents. An approximation to such a computation for the earth's atmosphere has been made by Ferrel and subsequent writers on meteorology, but the smooth theoretical atmospheric circulation of theory is much interfered with by the actual asperities of the earth's surface and by differences in temperature and density, in a vertical sense, due to the influence of the sun's rays.

To such an extent as the emerging continents became physical barriers to the oceanic circulation demanded by theory, the course of currents and incidentally their density and temperature have become modified. The north and south [illegible] tions taken by their [illegible] whole problem that a [illegible] for limited areas of coast, is in most cases still to be attained. Still, the broad outlines of dis[illegible] currents and their temperatures are fairly well known. We have learned that the temperature of the sea in which they live, within certain narrow limits, controls the distribution of marine invertebrates. Whatever the tolerance they may exhibit, and different species differ in this respect, there are distinct boundaries set to their distribution in the differences of temperature brought about by the circulation of oceanic waters. Whether these differences limit the range of faunas by direct action on the individuals or by their effect on the development of their progeny or by limiting their normal food supply has not yet been demonstrated; but it seems quite certain that in the larval stages the young invertebrates are markedly more susceptible to differences of temperature than adult animals, and, in the case of the oyster, Brooks found that a difference of two or three degrees Fahrenheit in the temperature of the water was sufficient to kill the whole larval brood. By inhibiting natural increase, therefore, a species may be as sharply limited in its permanent range as if material barriers interposed.

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[1] Manuscript received by the Secretary of the Society May 23, 1911.

There are two principal ways in which the sea temperature of a given region may be decided, apart from the normal amount of direct heat it may receive daily from the sun. One of these is due to the invasion of a region by an oceanic current, properly so called (that is, a body of water with motion in a definite direction usually differing from the sea about it in temperature, and more or less distinctly laterally limited), analogous to a river on a land surface in its relation to the adjacent sea. Such a current may carry cool water into a warmer region, or warm water into a cooler region, and by the temperature and evaporated moisture it gives off may also alter the aerial and terrestrial climates of the region invaded. Such examples as the Gulf Stream or the Equatorial current will occur to every one reflecting on the subject.

The rate and direction of such currents are determined, first of all, by the friction of the trade winds on the surface of the sea; secondly, by the land barriers encountered, and to a less extent by barometric pressure, differences of density due to concentration of saline matter and other minor factors.

The other way in which sea temperatures are affected is due to oceanic circulation independent of the friction of the winds, and which would occur if there were no winds at the surface of the sea. The rotation of the earth causes a lagging of the surface waters and a welling up on the western shores of continents of colder bottom waters when the contour of the sea bottom is favorable. The evaporation from surface waters in the tropics increases the salinity and density of the water affected, and there is a constant interchange of less dense cold polar waters with those of the tropics. The waters of the deeps are nearly always of polar temperature. The movements of the tides impinging on continental shores aid in this system of circulation.

It does not seem possible, under conditions of atmosphere approximating those of the present time, that there should ever have been a time when the tropic seas were not perceptibly warmer than the polar waters, though the latter may have been much warmer than at present. As soon as marine animals developed to a stage where temperature became a factor in their physiological history, it was inevitable that faunas should develop, and the more susceptible the inhabitants of the sea became the more distinctly faunas would become limited.

Of course, the development of the food supply, itself dependent on the sea temperature, the presence of large bodies of fresh water at the mouths of great rivers, the evolution of destructive gases arising from the sea bottom, or the invasion of limited areas of sea by noxious salts derived

from land areas, or submarine plutonic action altering the temperature or the chemical constitution of the sea water locally—all might at times have a temporary influence of some importance, but necessarily of a trifling kind compared with the two chief factors above mentioned, the currents and the oceanic circulation due to permanent cosmic causes of the first order of magnitude.

When we find the shore fauna of the eastern coast of South America practically the same on the shores north and south of the Amazon estuary we conclude that the distribution of the fauna antedates the existence of the estuary. When we find the boreal fauna extending down the eastern coast of North America, with representatives as far south as Georgia, we infer, what is proved by hydrographic investigation, that the Polar current is represented by an inshore band of cold water. We find on the Pacific coast of America the Oregonian fauna coinciding in distribution with the divaricating branches of the North Pacific current; the Peruvian fauna with those of the Humboldt or Peruvian current; on the Asiatic coast the Kuro Siwo and the Japanese fauna, the Okhotsk fauna and the Kamchatka current, are practically coincident. All over the world the close association of the range of temperature-bearing waters and marine faunas is recognizable, though occasionally less clear on account of the intervention of land barriers or minor causes.

When sudden changes of faunal characteristics occur in successive fossil faunas in the Tertiary, as at the end of the Oligocene and the beginning of our Chesapeake Miocene in the southern part of our coastal plain, though no orographic changes or unconformities appear on the spot, we are justified in concluding that changes at a distance have taken place which have altered the course of ocean currents and consequently have brought about local changes of temperature.

If it be possible to lay down with approximate accuracy the distribution of land at no matter what distance of geologic time, an application of the principles governing the distribution of ocean currents and the circulation of oceanic waters should enable the geologist to map the approximate distribution of the marine faunas at that epoch, always provided the difference of sea temperatures between the tropics and the Polar sea was at that period sufficient to affect organic life then existing in the ocean.

VALUE OF FLORAL EVIDENCE IN MARINE STRATA AS INDICATIVE OF NEARNESS OF SHORES[1]

BY DAVID WHITE

In discussing, from the paleogeographic standpoint, the occurrence of plants in limestones or other marine sediments primary consideration must scrupulously be given, first, to the kind of plants, and, second, to the condition of the plants.

In illustration of the first of these considerations it is hardly necessary to remark that algæ of marine types, though they may be blown along the beach and into coastwise dunes, are not likely to find a place in epicontinental fresh-water basins nor, except in the rarest instances, in eolian desert deposits. Neither, on the contrary, should one look in fresh-water coal basins for salt-marsh vegetation. So, also, though he may discover fresh-water limestones, which directly owe their very being to fresh-water algæ, one should not expect to find sweet-water thallophytes composing limestones in a marine environment. Each limestone contains calcareous or other algæ of its own kind. Otherwise do "men gather figs of thistles."

In practice, however, and for general paleogeographic uses algæ are apt to be of little need, or if needed they frequently are of little help, so very imperfect is our paleontologic knowledge of the small calcareous rock-building types, and so poorly preserved are usually the others whether in rocks of organic or terrigenous origin. Therefore, in the present discussion, further consideration will be confined to land plants; and, since the question is one of geographic values, to vascular only. This brings us, in our weighing of fossil plant criteria, to the second important point, namely, the condition of the plants themselves.

The occurrence of remains of land plants in limestone is uncommon enough always to attract the attention of the geologist, but the discovery of well preserved specimens, especially leaves, in a limestone formation is so exceedingly rare as never to fail to excite comment. In fact finding good specimens of land plants in the company of marine invertebrates in any place is worthy of mention, regardless of the sedimentary circumstances.

It is worth while in this connection to give brief attention to the conditions now to be observed and the processes now in operation in the seas of the present day. The reports of the *Blake*, the *Challenger*, and the

[1] Manuscript received by the Secretary of the Society May 23, 1911.

Albatross show that in certain regions of terrigenous deposits, especially within the tropics, vegetal refuse is abundant on the ocean bottom, even at depths of more than 2,000 fathoms. Thus Agassiz states that

"While dredging to the leeward of the Caribbean Islands, we could not fail to notice the large accumulation of vegetable matter and of land debris brought up from deep water many miles from the shore. It was not an uncommon thing to find at a depth of over one thousand fathoms, ten or fifteen miles from land, masses of leaves, pieces of bamboo and of sugar-cane, dead land shells, and other land debris, undoubtedly blown out to sea by the prevailing tradewinds. We frequently found floating on the surface masses of vegetation, more or less water-logged, and ready to sink. The contents of some of our trawls would certainly have puzzled a palæontologist; between the deep-water forms of crustacea, annelids, fishes, echinoderms, sponges, etcetera, and the mango and orange leaves mingled with branches of bamboo, nutmegs, and land shells, both animal and vegetable forms being in great profusion, he would have found it difficult to decide whether he had to deal with a marine or a land fauna. Such a haul from some fossil deposit would naturally be explained as representing a shallow estuary surrounded by forests, and yet the depth might have been fifteen hundred fathoms. This large amount of vegetable matter, thus carried out to sea, seems to have a material effect in increasing, in certain localities, the number of marine forms."[2]

The descriptions of the bottom deposits explored by the *Challenger*[3] mention the occurrence of twigs, woods, and seeds at a depth of 800 fathoms near Ki Islands, and the presence of twigs and leaves within 20 fathoms off the coast of Amboina Island, both localities being west of New Guinea. Palm fruits and fragments of wood and bark were found at a depth of 2,150 fathoms in the group of islands south of Mindanao, and fragments of leaves, stems, and wood, the latter overgrown with *Serpula*, were dredged from a depth of 1,050 fathoms at a station about 50 miles off the west coast of Luzon.

Agassiz, in his account of the explorations of the *Albatross* off the west coast of Central America, notes that:

"A very fine mud was the characteristic bottom we brought, often very sticky, and enough of it usually remained in the trawl, even when coming up from depths of 2,000 fathoms, materially to interfere with the assorting of the specimens contained in our hauls. This mud continued all the way from the Galapagos to Acapulco, and up to the mouth of the Gulf of California, where it became still more of an impediment to dredging, so that little work was done until we passed the Tres Marias. Even then the trawl was ordinarily well filled with mud, and with it came up the usual supply of logs, branches, twigs, and decayed vegetable matter.

[2] Bull. Mus. Com. Zool., Harvard Coll., vol. xiv, p. 391.
[3] Deep-sea deposits, pp. 95, 97, 99, 101.

"On going farther north, into the Gulf of California, the nature of the bottom did not change materially from what it had been along the coast from Acapulco to Cape Corrientes; it was the same viscid mud, mixed occasionally with *Globigerinæ* and masses of vegetable matter. So we found the trawling most difficult from the weight of the mud brought up, but occasionally a haul was made which more than repaid us for the time spent on the less productive ones.

"In the dredgings of the *Blake* in the Gulf of Mexico, off the West Indies, and in the Caribbean, my attention had already been called to the immense amount of vegetable matter dredged up from a depth of over 1,500 fathoms on the lee side of the West India Islands. But in none of the dredgings we made on the Atlantic side of the Isthmus did we come upon such masses of decomposed vegetable matter as we found on this expedition. There was hardly a haul taken which did not supply a large quantity of water-logged wood, and more or less fresh twigs, leaves, seeds, and fruits, in all possible stages of decomposition."[4]

In another account he refers again[5] to the abundance of water-logged wood, leaves, seeds, etcetera, "in all possible stages of decomposition," adding that "this was especially noteworthy in the line from the mainland to Cocos Island." On that portion of the cruise extending across the Humboldt current from the Panama coast to the Galapagos Islands Agassiz observed[6] that a few fragments of leaves were obtained at a depth of over 1,700 fathoms at a point nearly half way between Cape San Francisco and the Galapagos Islands.

With reference to the volume of terrigenous deposits Agassiz remarks:[7]

"From the investigations made this year by the *Albatross*, I am more inclined to assume that the true cause of the absence of coral reefs on the west coast of Central Africa is due to the immense amount of silt which is brought down the hill and mountain sides every rainy season, and which simply covers the floor of the ocean to a very considerable distance from the land, the land deposits being found by us even on the line from the Galapagos to Acapulco at the most distant point from the shore to the side or extremities. The mud in Panama Bay to the hundred-fathom line is something extraordinary, and its influence on the growth of coral reefs is undoubtedly greatly increased from the large amount of decomposed vegetable matter which is mixed with the terrigenous deposits."

Again, in his notes on the exploration of the Gulf of California, we find that[8] "the trawl was usually well filled with mud," and that "the mud gave up the usual supply of logs, branches, twigs, and decayed vegetable matter."

[4] Bull. Mus. Comp. Zool., Harvard Coll., vol. xxiii, p. 12.
[5] Op. cit., vol. xxi, 1891, p. 187.
[6] Loc. cit., p. 190.
[7] Loc. cit., p. 195.
[8] Loc. cit., p. 197.

While the striking instances cited from the reports just mentioned[9] are important as showing both the distance to which vegetal refuse may, under favorable circumstances, be deposited, and the depth at which it may be found in terrigenous deposits, two important points should not be lost from view: first, that most of the material is found in regions of deposition of terrigenous matter, and, second, that in most cases the localities are in close proximity to the land. Even in the latter cases the organic matter is described as more or less decayed, while in the most remarkable series, extending over a stretch of 500 miles or more from the Central American coast to the Galapagos Islands, we find that all the material was "in varying stages of decomposition." At best the leaf fragments reported appear to have been confined to types with hard, siliceous, or thick cuticles, such as the palm and the bamboo. Only thick, leathery, dicotyledonous types like the orange and the mangrove seem to have been in recognizable condition in the dredging near the land. Only in very rare cases do we find any quantity of land plant material under the conditions of deposition of the purer carbonates at any considerable distance from the coast, and in these cases the material embraces only the more imperishable parts of the plants.

The significance of the evidence offered by plant remains found fossil in marine deposits depends mainly on the state of their preservation. If the material is macerated, corroded, rolled, defoliated, skeletonized, incrusted, or bears other signs of having been for some time in the water, it is liable to have been transported for some distance, judgment of the possible distance or time being dependent to an extent on the progress of the work of the destructive agencies. If long in sea water the fragments are likely to bear the marks of the abundant marine organisms, particularly if in tropical sea water. On the other hand, the occurrence of clean, unbroken, smooth leaves, and particularly of large segments of fern fronds, with their full complement of carbonaceous residues, is prima facie evidence of minimum exposure to water and of the least subjection to the action of swift currents or waves. In fact, it may be stated that except in extraordinary or most fortuitous cases clean and distinct leaves are never found in limestone strata, whether marine or fresh water, except in a very near relation to the land on which they had origin. Farther from land they are more indistinct, poorly preserved, fragmentary and deformed, as well as wasted. In most marine sediments the only vestiges of land plants that may be found are confined to the most indestructible

[9] For illustrations of long transportation see Lyell: Principles of geology, 1867, vol. ii, p. 361; vol. i, p. 445; *Challenger* narrative, vol. i, pt. 2, p. 679; Bates: Naturalist on the River Amazon, 1863, p. 389.

parts—that is, seed envelopes, spore covers, pollen shells, and fragments of wood and stems, especially of resinous or very dense types. This is due to several causes:

1. On account of their fragility leaves, especially those of ferns, are very quickly rumpled, curled, torn, or shredded in water transport, and if long en route are soon reduced to fine refuse ("Häcksel") by wind, wave, or current action. Leaves become submerged sooner than trunks, twigs, etcetera; they are promptly attacked by the pelagic animal life, and their mesophyll quickly decays as the result of microbian action.

2. On reaching salt water they are very quickly covered by slimes, animal and vegetal organisms, which coat or corrode the surface, so that unless buried promptly they can not leave clean or clear-cut imprints, even if submerged beneath cold waters. The observations of several marine naturalists go to show that signs of the destructive agencies, exclusive of wave and current, are generally evident in less than two days from the moment of marine submersion.

3. Decay proceeds more rapidly in salt than in fresh water, by reason of the abundance and variety of the attacking animal types, and also, it is said,[10] on account of the greater amounts of sulphates and carbonates in sea water, which by decomposition in the presence of organic acids facilitate the oxidation (destruction) of the plant tissue. Decay proceeds even at great depths and in low temperatures; but these are regions of slow deposition, so that there is correspondingly greater time for corrosion and putrefaction, or even total destruction, before the organic matter becomes protected by an oxygen-excluding sedimentary cover.

4. The conditions of open marine deposition preclude the development of a partial or completely aseptic or toxic water-cover, such as may take place in fresh or land-locked water bodies.

5. Regions of distinctly calcareous deposition, or of limestone formation—that is, regions comparatively free from terrigenous sediments—are apt to be far from the mouths of rivers and from currents carrying land sediments, therefore plants are not likely to reach them in good condition unless the deposits are close to shore or coast. If rapidly transported they are liable to damage by wave action and other commotion of the current. Furthermore, in most regions of such sedimentation the accumulation of the rock-forming material is so slow that the most enduring parts of the plants may seldom escape decay before they are so far buried as to make permanent their forms.

The fresher the vegetal material the better the chances that some per-

[10] *Challenger* reports: Deep-sea deposits, p. 256.

tion of it may leave a recognizable impression; or, again, the greater the influx of terrigenous matter, including vegetal debris, with consequently more rapid sedimentary deposition, the more likely the burial of a part of the plant refuse in recognizable condition.

It would appear that the areas of most abundant terrigenous muds, with plant ingredients, between Central America and the Cocos or the Galapagos Islands, are regions of deposition of somewhat carbonaceous shales, probably more or less calcareous in certain districts, and possibly comparable to those of the Upper Devonian in portions of Ohio. They contain the raw materials for the petroleum and natural gas of a future geologic age, when portions of partially decayed plant refuse in the region of the western Pacific Islands will be found in calcareous shales or shaly ferriferous or manganiferous limestones.

If, now, we turn to examine the geological conditions attending the occurrence of well preserved plants in limestones or other clearly marine strata of geologic age, we find that in nearly every case of reasonably good preservation of leaf or fern material there is associated geologic evidence of the existence of land not far distant. The best preserved filicoid types of the Ithaca group are associated with contemporaneous channel cutting and other local shoal water phenomena. The relatively well preserved material in the Portage (Hatch), near Naples, New York, is said to be associated with coaly streaks, which I regard as indicative of probable local flats or possibly a partially land-locked or temporarily lagoonal environment. The splendid *Archæopteris* fronds of the Catskill and Chemung in southern New York and northeastern Pennsylvania are in most cases stratigraphically associated with contemporaneous erosion planes, truncated mud beds, carbonaceous wedges, breccias or conglomerates—all indicative of subaerial exposure or approximate littoral conditions. So, also, with the better grade of material from the Burgoon and the lower Pocono. The floras in the Canaan limestones of the Buckhannon quadrangle in West Virginia, in the Bluefield shale formation at Abbs Valley, in southwest Virginia, and in the Bangor of Alabama, appear in interbedded shales containing thin coals; in sand wedges of littoral, or possibly shoal, origin; or if in impure limestones, as in West Virginia, at horizons of limestone breccias. In fact, the discovery of these plants is very important, as drawing attention to the occurrence of diastrophic movement during the long period of Mississippian marine sedimentation. The floras and sections have not yet been studied sufficiently to show how many uplifts took place in one region or another of the Appalachian trough during Mississippian time. According to the

writer's opinion, the examples cited not only point out movements which may subdivide Mississippian time, but they also lend support to the views of Ulrich as to the shallowness of the Mississippian seas.

In the abundant and familiar cases of the association of finely preserved leaves and fern fronds with marine shells in the roofs of coals in all the epochs of vascular land plant life, Paleozoic, Mesozoic, Cenozoic, and Recent, and in various regions of the world, the coals and their underlying old soils bear witness to their paleogeographic relations as coastal or lagoonal swamps which at the moment of molluscan invasion had just been inundated by the sea.[11]

The deductions drawn from the occurrence and conditions of land plant material in the oceanic areas of today and from the stratigraphic relations and state of the corresponding fossils found in the older deposits, appear fully to justify the conclusion that the presence of clean and well preserved leaf material in limestones or other marine sediments constitutes satisfactory proof of proximity of the deposit to land; as, conversely, the occurrence of water-worn, partially decayed, incrusted, or corroded material permits the conclusion that the specimens may have been for some time in water and are therefore liable to have been transported for some distance. Unfortunately, the evidence of fossil plants, though of the highest value in paleogeographic deductions, is so rare as usually to be wanting on the occasions of greatest need.

ARE THE FOSSILS OF THE DOLOMITES INDICATIVE OF SHALLOW, HIGHLY SALINE AND WARM WATER SEAS?[1]

BY STUART WELLER

It must be recognized at the outset, in the discussion of the subject which has been assigned me, that all dolomitic formations have not been deposited under like conditions. In such magnesian beds as are present in the Cayugan period of the Silurian, we find a most peculiar fauna, constituted almost wholly of the strange Eurypteroid arthropods whose fossil remains are almost never found in association with typical marine faunas, but which are present in situations, such, for instance, as the plant-bearing beds of the Pennsylvanian, which indicate that they must have lived in non-marine waters. The stratigraphic association of these Cayugan, Eurypterus-bearing beds with beds of salt and gypsum would

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[1] Manuscript received by the Secretary of the Society May 23, 1911.

[11] The plant-bearing limestones of the Purbeck on the Dorset coast lie on the dirt beds (old soils), on which the vegetation grew.

suggest at once that the waters of the period were highly saline and perhaps shallow; but, so far as I am aware, there is no inherent characteristic of the fossil Eurypterus which can in any way suggest that it may not have been a truly marine organism, and our conclusion that it was not such an organism is drawn from the physical surroundings of the fossil itself, rather than that the physical conditions are what we believe them to be on account of some peculiarity of the fossil.

I believe, however, that the dolomitic formations which it was intended that I should discuss are the far more widespread formations of Paleözoic time, such as the Niagaran and Galena formations of the Upper Mississippi Valley, and it is altogether permissible to assume that these formations were deposited under very different conditions than were the Waterlime beds of the Cayugan. In most dolomitic formations, such as those just mentioned, the fossils present are preserved in a very imperfect condition, almost always in the form of casts and moulds, and are often more or less obliterated, so that accurate specific identifications are frequently or commonly difficult or impossible, and this unsatisfactory condition of the fossils themselves must be kept in mind in connection with the comparisons of faunas to be made later. In nearly all cases the fossils of the calcareous beds are better preserved, more numerous, and more readily identifiable than those in the dolomites.

A comparison of fossil faunas preserved in dolomitic formations with faunas of similar age in calcareous beds ought to show whether the life of these ancient seas was notably reacted upon by the conditions which have been responsible for the existence of our conspicuous dolomitic formations. A comparison of this sort has been attempted between the fauna of the dolomitic Galena formation of Illinois, Wisconsin, Iowa, and Minnesota and the fauna of the typical Trenton limestone of the east, two formations which are believed to be essentially contemporaneous. A census of the Galena fauna, in which it has been the purpose to exclude all forms except those which occur in the dolomitic facies of the formation, has been compiled. Perhaps the most characteristic member of the fauna is Receptaculites, several species of which genus are recorded, of which *R. oweni* is the most common. This genus is represented in the typical calcareous Trenton limestone of New Jersey and elsewhere in the East, and the most characteristic Galena species occurs in such great numbers in the upper portion of the calcareous Kimmswick limestone of southeastern Missouri that this formation was called the Receptaculite limestone by the early Missouri geologists. The corals are sparsely represented in the fauna, an undetermined species of Streptelasma being the

only form worthy of record, and this genus is one which is well represented in the calcareous limestone of the East. The Echinodermata are so unusual, and when present so poorly preserved, that they may be ignored in this place. The Bryozoa are represented by a few forms too poorly preserved for accurate determination, but the commonest form is probably Prasopora, a genus which is one of the most conspicuous in the calcareous Trenton elsewhere. The Brachiopoda have a goodly representation, the following genera being recorded: Lingula, Platystrophia, Dalmanella, Dinorthis, Orthis, Rafinesquina, Plectambonites, Leptæna, Rhynchotrema, and Cyclospira. All of these genera are present in abundance in calcareous formations of essentially the same age as the Galena, and there is no single species in the Galena which does not occur in these calcareous formations. The Pelecypods are represented by nine genera, as follows: Byssonychia, Clionychia, Orthodesma, Cyrtodonta, Vanuxemia, Ctenodonta, and Cuneamya. As in the case of the Brachiopods, all of these genera are typically represented in calcareous beds elsewhere, although one or two of the species recorded have been described exclusively from the Galena formation. The Gastropoda constitute the largest single element in the fauna, fifteen genera being recorded, as follows: Bellerophon, Phanerotrema, Lophospira, Liospira, Clathrospira, Hormotoma, Cœlocaulis, Eccyliopterus, Helicotoma, Ecculiomphalus, Maclurea, Maclurina, Trochonema, Holopea, and Fusispira. A small minority of the species of these Gastropoda have been described from the Galena, and are not as yet recognized elsewhere, but every one of the genera and most of the species are well represented in calcarous formations of similar age. The Cephalopoda are represented by the genera Cameroceras, Orthoceras, Triptoceras, Oncoceras, and Cyrtoceras, and, as in the case of the other groups of organisms mentioned, these, too, are well represented by the identical species in calcareous formations. Only one trilobite genus, Illænus, is recorded, but this genus, and even the same species, occurs in abundance in contemporaneous calcareous beds.

From the facts gleaned in suc ha census of the Galena faunas, there seems to be no evidence whatever for concluding that the life conditions in the Galena sea were in any respect different from those of the basins which are now represented by purely calcareous sediments. There is no single characteristic of the fauna which would suggest that the waters were more saline, warmer, or shallower than the seas in which, for instance, the Trenton limestone of the East or the Kimmswick limestone of southern Illinois and Missouri were deposited. It is ordinarily conceded that an intensification of the salinity of sea waters produces a

depauperation of the fauna, but the fauna of the Galena is notably composed of the larger and more robust forms, probably because the smaller and more delicate shells have been obliterated by secondary chemical changes in the sediments.

A study of the fauna of the dolomitic Silurian formations of northern Illinois and southern Wisconsin, in connection with the faunas of contemporaneous non-magnesian formations elsewhere, affords another opportunity for similar comparison. In this fauna there are recorded fifty or more species of corals distributed among some twenty genera. All of these genera and many of the species occur elsewhere in non-magnesian formations, many of them in the Ohio Valley. Among the Crinoidea seventy or more species are known, belonging to nearly thirty genera. Most of these genera and many of the species are well represented elsewhere in America in non-magnesian formations of essentially the same age, and other genera, not known outside this dolomitic formation in America, are known from non-magnesian formations in northern Europe. The Cystoidea, Brachiopoda, Mollusca, and Trilobita all tell the same story as the Corals and the Crinoids. All these groups are represented in the fauna by many genera and species; the genera are in almost all cases well represented in non-magnesian formations, and a large majority of the species also are common elsewhere. From the consideration of this fauna it seems impossible to postulate that the sea in which it lived was any more saline, shallower, or warmer than the contemporaneous seas whose life is now preserved in non-magnesian formations, either calcareous or argillaceous.

It is only in the Guelph formation of the Silurian and in its equivalents that we may perhaps detect a faunal element indicative of greater salinity, in the association of the more or less diminutive and delicate-shelled species with the large and thick-shelled brachiopods, Trimerella, Monomerella, and Rhinobolus, and the similarly thick-shelled pelecypods, Megalomus and Goniophora. The suggestion that this assemblage of forms in association with the abundance of reef-building corals indicates a more than normally saline sea has been made by Clarke and Ruedemann, and I am not ready to dispute the truth of their conclusion, but it must be recognized that this same fauna occurs in non-magnesian sediments in the higher beds of the Gotland limestone of Sweden.

Other widespread dolomitic formations in the American Paleozoics do not lend themselves so readily to the solution of the problem in hand. The widely distributed dolomitic formations of late Cambrian and early Ordovician age are in general rarely fossiliferous, so that their known

faunas are altogether too meager to permit their being used as a basis for any conclusion in the matter. In the case of certain Devonian dolomitic formations—as, for instance, the Middle Devonian beds at Milwaukee, Wisconsin, and the dolomitic beds which are present in the Devonian section of Iowa—we have faunas constituted of species which, almost without exception, occur elsewhere in calcareous sediments. The same is true of certain Ordovician formations other than the Galena.

In conclusion it may be stated that from the evidence of the fossils alone there seems to be no reason for assuming that our widespread dolomitic formations of Paleozoic age have been deposited under conditions which are notably different, as regards salinity, temperature, or depth, from those under which non-magnesian formations, either argillaceous or calcareous, have been laid down. Chemical geologists are almost unanimously agreed that in general the dolomitization of limestone is a secondary process, and the paleontological evidence, so far as it is available, seems to substantiate that view. Formations now dolomite were in all probability originally deposited as limestones, and have been altered to dolomites since their original deposition, while other beds entirely similar in original condition have not been modified, but persist to the present time as true limestones.

STRATIGRAPHIC SIGNIFICANCE OF THE WIDE DISTRIBUTION OF GRAPTOLITES [1]

BY RUDOLF RUEDEMANN

I have been asked by your President to speak on the stratigraphic significance of the wide distribution of graptolites.

This title assumes the wide distribution of the graptolites as an established fact. It is such, but with a certain qualification that will be considered later.

The closer investigation of the graptolites in Europe, America, and in Australia has brought out the fact of the presence in all three continents of the common or guide graptolites, of the Ordovicic, at least, and of the general agreement of the sequence of the zones. The distribution of an important fraction (roughly, at least one-third) is world-wide.

The structure of the graptolites has shown that the earlier forms without axes (Axonolipa) were for the greatest part pseudoplanktonic—that is, they drifted about fastened to seaweed—while the later Axonophora were planktonic or floated by means of apparatus of their own.

[1] Manuscript received by the Secretary of the Society May 23, 1911.

The combined facts of the world-wide distribution of the more common graptolites and of their planktonic mode of life, together with the restriction of the graptolites to either the edges of continents or former deep submarginal troughs, lead to the conclusion that the home of the graptolites was in the practically permanent oceanic basins, and that they were but strangers in the relatively occasional epicontinental seas.

This conceded, it further follows that these oceans were connected, and that the graptolite horizons of world-wide distribution indicate synchrony and not merely homotaxy, and thus are probable means of world-wide correlation; further, that where the graptolites are found in a series of zones they indicate near-oceanic conditions—that is, proximity to an ocean—the presence of oceanic currents, which carried these planktonic organisms through the basin, and possibly, also, a greater depth of water than usually occupied continental basins and troughs.

Each of these conclusions requires, again, some qualification and explanation.

First, although a certain percentage of the species in every zone may be world-wide, others differ sufficiently to warrant the recognition of provincial features also among the graptolites. The minor provincial differences correspond apparently to the opposite sides of oceanic basins, the larger ones to the different oceans themselves. It follows from this that where the latter differences are pronounced, as in part of Ordovicic time, that the oceans must on one hand have been in sufficient intercommunication to permit world-wide distribution of the common graptolites by the currents, and still sufficiently defined and separated to also favor the development of provincial characters in the plankton, or, in other words, the relative areas of water and land were not materially different from the present condition.

The inference that the graptolites were but strangers in the epicontinental seas explains the observation that they occur there only sporadically—as, for instance, the zone of *Monograptus clintonensis* and *Retiograptus venosus,* in the upper Williamson shale of the Clinton of western New York. Where graptolite faunules appear as abruptly and for such a brief period only, as in the Williamson, it is safe to say that this incursion is caused by the breaking of an ocean current through a barrier, and its free, though short-lived, passage through the basin. In the case of the Williamson shale I am convinced that the eastern embayment of the Mississippi basin, mapped by Professor Schuchert for the Wolcott-Williamson stage, connected at this brief stage with the Appalachian basin,

thereby allowing a current to enter from the east and bring in the multitude of graptolites. It agrees with this conclusion that the graptolite horizon of the Williamson continues farthest east of all the Clinton beds recognized in western New York. A similar invasion of graptolites, to which we shall recur later, from the east as far west as Cincinnati had already taken place in Utica time.

Where the graptolites occur in a longer series of beds, they indicate a trough or basin near an ocean. In the memoir on North American graptolites I have pointed out the remarkable continuity of the formation of graptolitiferous beds in certain regions as indicating that deposition in such areas was more nearly continuous than seems to have been the case in most other areas of fossiliferous rocks, or, in other words, that the conditions producing the deposition of graptolite shales tended to persist for a long time in the same region. From this it is inferred that long series of graptolite zones indicate the former existence of long persisting deep troughs in the places where these series are now found. In most, if not all, cases these troughs correspond to the sites of Paleozoic geosynclines.

But even where the deposition of graptolite beds was apparently continuous for a long time, as in our Levis basin, the successive horizons are not connected by transitional beds, but marked by the rather abrupt appearance of new forms. This means that either our knowledge is still imperfect and the connecting subzones have not yet been discovered—which is certainly true in some cases—or that many of them do not exist in these basins. Localities like the Deep Kill, where several zones could be followed bed for bed, would suggest that such transitional zones are missing there. This fact, coupled with the planktonic mode of life of the graptolites, indicates that this uninterrupted development has to be sought in the oceanic basins, and that the horizons seen in the graptolite beds are for a large part but snapshots at intervals out of this continuous development in the oceans. The non-graptolitiferous intervals mark not only the temporary absence of currents sweeping in from the ocean and carrying the graptolites through the channel, but they probably also cover intervals of non-deposition.[2]

Since the Axonolipa were fastened to seaweeds and the Axonophora floated free (but judging from the relative stiffness of their axes, prob-

[2] At least Doctor Ulrich, who has given me the benefit of his extensive observations in this problem with his well known liberality, writes me that he has stratigraphic evidence that deposition in these submarginal basins was as much interrupted as that in the more inland basins.

ably outside the reach of the waves and in moderate depths of the sea), and both were dependent on oceanic currents for transportation, it is thought impossible that they could have entered culs-de-sac such as the Baltic Sea in any considerable quantities, and their abundant and continued presence is taken as indicating the deposition of the beds in either the ocean or a sea with free egress and ingress.

Scattered occurrences of graptolites may occur in epicontinental seas by the slow action of an entering surface current in a tropical hypersaline sea, such as the Red Sea of today, or through an entering bottom current in a brackish sea, as the Baltic Sea now is.

The black carbonaceous graptolite shales do not indicate conditions of a nearly inclosed basin, such as is now exampled by the Black Sea, for in the latter life exists only near the surface, and the Axonophora, at least, quite surely lived in the more quiet depths, nor would in such a basin be found the great mass of floating seaweed to support the Axonolipa. Many different graptolite zones occur, as a rule, in a small thickness of rock, but sometimes they are also embedded in coarser sediments. The most essential requisite for the formation of the black fine grained graptolite shales is, therefore, not the depth, but the tranquillity of the water. The graptolite shales, therefore, indicate a zone between the agitated water, where coarser sediments are deposited, and the dead or currentless water of the deeper sea. Their longitudinal distribution, then, also indicates the direction of a coastline, which has to be sought on the farther side of a parallel band of coarser littoral sediments, and two such flanking littoral bands may be looked for in narrow channels like the Levis Channel.

The last corollary from the world-wide oceanic distribution of the index graptolites is that their zones are not homotaxial, but virtually synchronous, these graptolites thus being index fossils for absolute time correlation. This conclusion postulates that the new graptolite species either devoloped in all oceans *pari passu*, or that if new forms originated in one oceanic basin they so rapidly spread into the others that deposition of rock did not take place sufficiently quick to record this migration in the rocks. The former hypothesis of the uniform development of the index graptolites in all oceans would presuppose the absence of any physical differences in the oceans, and it fails to account for the provincial forms; the latter hypothesis, of the immediate diffusion of new forms, is apparently not quite supported by all the facts, for some of the common graptolites do actually appear later in one basin than in another. It is thus claimed, to cite one instance, by T. S. Hall that in Australia *Loganograptus logani* appears much later in the graptolite horizons than

in Europe, and we may add that we have found the same late appearance in the Deep Kill beds of New York. It is hence apparent that these graptolites actually traveled from one basin to another, and with different rate perhaps through their position in different depths. The great majority of the world-wide species, however, appeared together. If these at all traveled with the ocean currents they must have, after once entering these currents, been diffused in a, geologically speaking, immeasurably short time or have appeared synchronously. In that case the identical graptolite horizons are the surest means of intercontinental correlation.

We will now briefly consider the principal cases of wide distribution of graptolites.

The zone of *Dictyonema flabelliforme,* which in Europe characterizes the boundary between the Cambric and Ordovicic, is known as yet from the Atlantic basin only, and its occurrence in the base of the graptolite zones of the Levis Channel would indicate early Atlantic connections. This horizon in Europe was first made the top of the Cambric, and lately the bottom of the Ordovicic, and it has been also assigned in America to the top of the first or bottom of the second system by several authors.[3]

The Beekmantown zones, as represented by the Deep Kill shales of New York, are essentially Atlantic in their composition, but with some undoubted Pacific elements, indicative of some connection with the Pacific at times. The occurrence of these Beekmantown graptolites in Arkansas and Nevada would seem to suggest a transcontinental connection with the Pacific. The principal Atlantic graptolites are fully at home in the Pacific. We find, for instance, one horizon in Victoria, Australia, characterized by *Didymograptus bifidus, D. extensus* (?), *Tetragraptus quadribrachiatus, T. serra, T. fruticosus,* Dichograptus, *Phyllograptus typus,* and P. sp. And the fact that the differences in the time of appearance of some important forms between Australia and Europe (as the later appearance of *Loganograptus logani* and earlier appearance of *Didymograptus bifidus* in Australia) are exactly duplicated in our Deep Kill zones, and the presence of *Gonigraptus thureaui* in both Australia and the Levis Channel are strong arguments not only in favor of some connection of the Levis basin with the Pacific Ocean, but even of

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[3] Doctor Ulrich writes me regarding the age of this horizon: "The *Dictyonema flabelliforme* and the main Tetragraptus zones I regard as in large part if not entirely older than the lower part of the 4,200 feet of Canadian (Beekmantown) limestones in central Pennsylvania. This is indicated by the facts (1) that mutations of *Didymograptus bifidus, D. amplus,* and *Phyllograptus ilicifolius* occur in northern Arkansas only in lower Canadian deposits, and (2) that the conglomerates at Quebec contain late middle or upper Ozarkian trilobites."

the arrival of some of the forms of this far distant basin by a current from the west.

The writer has inclined to the view that this connection with the Pacific could have been transcontinental by means of the Beekmantown transgression. Doctor Ulrich, however, has arrived at a different view, "since the continental seas of the required size and location can not be established and indeed seem to have been impossible." He states in a letter to me his conception as follows:

"As I see it, the widely distributed graptolite faunas, like the Tetragraptus and Nemagraptus, attained their great dispersal solely by means of oceanic currents. The channels in whose deposits we now find these faunas were, as you yourself have indicated, thoroughfares for such currents. In the cases of the Levis, Athens, and Ouachita troughs, it seems to me demonstrable that they were channels connecting at both ends with Atlantic oceanic basins and that they passed around the inner sides (and thus separated off from the main mass of the continent) certain large marginal islands (Taconia, Appalachia, and Llano). As plotted on my maps, the Levis Channel passes up the Saint Lawrence to the east side of the Champlain Valley, and thence south to northern New Jersey, where it joins the Atlantic. The Athens Channel begins on the north at Chesapeake Bay, extends along the eastern side of the Appalachian Valley to central Alabama, beyond which it connects with the Gulf of Mexico. The Ouachita Channel connected with the Gulf through the Mississippi embayment, passed westward through central Arkansas and Oklahoma, and thence probably turned southward to open into some western part of the Gulf.

"How these graptolites got into the Pacific, or how those of the Pacific got into the Atlantic is a more difficult problem. Possibly the isthmian region was submerged at such times—or it may be that a channel across northwestern South America afforded the necessary means for communication. We do not know."

The graptolite fauna of the Normanskill shale, of approximate Black River age, is distinctly Atlantic in its aspect and is common to northeastern America and Europe. But some of its elements have also found their way into Arkansas and British Columbia and into the Pacific basin and Australia.

The leading species of the graptolite shales corresponding to the Upper Trenton (Magog shale) and of the Utica shale are again common to Europe and eastern North America and are Atlantic forms. In Utica time an arm of the Atlantic entered from the northeast, or Lower Saint Lawrence region, far on the continental platform, and, as indicated by the graptolite facies, had one or more outlets that completed a circuit back to the Atlantic, the current entering from the Saint Lawrence re-

gion, according to evidence found by the writer, in the prevailing direction of fossils in the Mohawk region. A few of our Utica forms, as *Diplograptus quadrimucronatus, Dicranograptus nicholsoni,* again have reached the Pacific basin, but not by way of a North American epicontinental sea.

The absence of typical graptolite shales in the Frankfort and Lorraine suggest that then the arms of the sea that spread over the continent, at this time from the south, were ending blind toward the northeast.

The Siluric, aside from small occurrences on our northeastern Atlantic border, has furnished only two occurrences of graptolites in the Williamson shale of the Clinton and a later one in the Niagaran of eastern Missouri. Since only the Upper Siluric graptolite faunas of the Atlantic basin are as yet known, no evidence as to the possible relationship of these faunules to other than the Atlantic basin is at hand.

In conclusion, I wish to emphasize the fact that inasmuch as the graptolites as planktonic organisms were able to cross the oceans and seas directly instead of creeping along the shores, as the littoral benthonic faunas did, they must not only have wandered infinitely faster and farther, but may even have gone in opposite directions to the coexistent littoral faunas. While the appearance of the latter proves the establishment of a bridge or littoral highway, that of the former often indicates the opening of an oceanic highway with currents as carriers for the graptolite fauna. And while the former, as a rule, are separated by the deep sea, the latter are connected by it.

PHYSICAL CONDITIONS UNDER WHICH PALEOZOIC CORAL REEFS WERE FORMED[1]

BY THOMAS WAYLAND VAUGHAN

CONTENTS

Definition and origin of Coral Reef

A coral reef is a ridge or mound of limestone, the upper surface of which lies, or lay at the time of its formation, near the level of the sea, and is predominantly composed of calcium carbonate secreted by organisms, of which the most important are corals. A coral reef is, therefore,

[1] Manuscript received by the Secretary of the Society May 23, 1911.
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primarily a limestone formed through the activity of organisms secreting carbonate of lime.

Since the physical conditions prevalent during the formation of fossil coral reefs can not be ascertained by direct observation, it is necessary to resort to the process of deduction. Evidence for establishing criteria may be derived from two sources: The first, through the study of the conditions under which modern reefs are formed, and the determination of the factors necessary for the physiologic activity to which large accumulations of calcium carbonate are due; the second, through the investigation of the physical character and the nature of the bedding or stratification of the sediments in which the fossil reefs are embedded. An attempt will be made to derive criteria from both these sources and to apply them in the elucidation of the problem.

Recent Coral Reefs

COMPOSITION

A modern coral reef is not entirely composed of the skeletons of corals, the remains of nullipores, mollusks, echinoids, and littoral foraminifera forming important constituents. Reef corals do not exclusively belong to the Madreporia, the Alcyonaria and Hydrozoa both contributing a certain quota of material. In the succeeding remarks the distribution of these groups of organisms with reference to depth and intensity of light, temperature, motion of the water, character of bottom, composition of the oceanic salts, and specific gravity of the water will be considered.

DEPTH OF WATER AND INTENSITY OF LIGHT

The literature on the maximum depth at which reef-building Madreporaria may grow vigorously is extensive, and there is practical unanimity among all investigators that 25 fathoms is the greatest depth at which they work effectively, although an occasional reef species may extend downward to a depth of 40 fathoms. The most luxuriant growth, however, is in shallower water, from just below low tide level to perhaps 10 or 15 fathoms. These bathymetric limits of the Madreporaria usually apply to the Alcyonarian *Heliopora* and *Tubipora*, the Hydroid *Millepora*, and the Nullipores, although *Heliopora* and *Millepora* in the Maldives are important constructional agents to depths between 35 and 40 fathoms, and Nullipores extend to a depth of 35 fathoms.[2]

Several factors besides pressure are correlated with increasing depth. One is the intensity of light. In this connection the following remarks

[2] J. Stanley Gardiner: Fauna and geography of the Maldive and Laccadive archipelagoes, pp. 342-326.

are quoted from Prof. Johan Hjort's article on "The *Michael Sars* North Atlantic Deep-Sea Expedition:" [3]

. . . "Now, if we calculate the depth to which the rays of the sun penetrate, after passing through the same distance in the water, assuming always that the rays are direct, and that the rate of obsorption is the same, we find that the rays will have passed through the same distance to reach a depth of 500 meters in 50 degrees north latitude that they will pass through to reach 650 meters in 33 degrees north latitude, or 300 meters in 67 degrees north latitude.

"However, the transparency of the water varies greatly in different regions. If we take the results of previous observations during different expeditions, we may set down the visible depth in the open sea as being, roughly, 50 meters in 33 degrees north latitude, 40 meters in 50 degrees north latitude, and 25 meters at the outside in the Norwegian Sea in 67 degrees north latitude. Taking this into consideration, we find that there will be the same *intensity* from the rectilinear rays—

"In 33 degrees north latitude, at about 800 meters' depth.

"In 50 degrees north latitude, at about 500 meters' depth.

"In 67 degrees north latitude, at about 200 meters' depth."

. . . .

"During the Atlantic cruise of the *Michael Sars* we undertook a series of measurements of the intensity of light with a photometer constructed by Dr. Helland-Hansen; to determine the intensity of the different color rays, Dr. Helland-Hansen made use of panchromatic plates and gelatine color-filters. The observation south and west of the Azores (that is to say, at the southern stations) showed that the rays of light strongly affected the plate at a depth of 100 meters. The red rays were weakest here, while the blue and ultra-violet rays were strongest. At a depth of 500 meters the blue and ultra-violet rays were still distinctly visible, and at a depth of 1,000 meters the ultra-violet rays were yet perceptible. In 1,700 meters, however, there was not the faintest trace of light, even after the plates had been exposed for two hours in broad daylight."

A natural experiment at the Tortugas shows the effect of light on the habitat of shallow-water species. The government wharf at Fort Jefferson is supported by iron piles coated with cement. On all the peripheral piles (on both ends and on both the landward and seaward sides of the wharf) there are many corals, while those in the permanently shaded area bear none at all. Species of reef corals placed in a light-proof live-car die after the light has been excluded for several weeks. Strong light is one of the essentials for the life of recent species of reef corals.[4]

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[3] This quotation is from a proof copy kindly loaned by Sir John Murray. The article, a lecture before the Royal Geographical Society, appears in the Geographical Journal, 1911; but as I have not, on June 22, seen the issue of the Magazine containing it, I can not give the page reference.

[4] The presence of commensal algæ (Zoanthoxellæ) is here noted, but a discussion of them and their functions would be too great a diversion.

Decrease in temperature with increase of depth in the ocean is well known.

TEMPERATURE

Dana long ago showed the minimum temperature of the year to be a critical factor in determining the possibility of reef corals living in a locality where conditions were otherwise favorable for their growth, and designated 68 degrees Fahrenheit as the lowest temperature these organisms could stand. The mean annual temperature of the water must be above 70 degrees Fahrenheit. Therefore a high temperature is necessary for the vigorous growth of reef-building corals.

The importance of high temperature for the secretion of carbonate of lime in quantity by marine organisms can best be presented by giving the words of Sir John Murray:[5]

"During the past year or two I have carefully collected all the available temperatures of the surface waters of the ocean, and from these have constructed a map showing the annual range of temperature in different regions of the ocean. This map shows that the surface of the sea may be grouped into five great zones, namely: (1) A nearly continuous equatorial zone, where the temperature is high and the range throughout the year does not exceed 10 degrees Fahrenheit. This zone includes all the principal coral-reef regions. (2 and 3) Two polar zones, where the temperature is low and the annual range likewise does not exceed 10 degrees Fahrenheit. In these zones there are relatively few lime-secreting organisms. (4 and 5) Two regions lying between the equatorial zone and the two polar zones, where a wide range of temperature occurs between the different seasons (the annual range amounting to as much as 52 degrees Fahrenheit in some places). In these temperate regions the secretion of carbonate of lime appears to be much more active in the warmer than in the colder months. It thus appears that the most favorable conditions for lime-secreting organisms are met with in the warm, equable tropical waters of the ocean, and here, as a matter of fact, we find the greatest development of corals and the largest number of lime-secreting pelagic organisms. In the polar areas and in the cold water of the deep sea there is, as is well known, a feeble development of all carbonate of lime structures in marine organisms.

"From experiments which have been carried out by Mr. Irvine and myself at the Granton Marine Station we have reason to believe that this distribution is dependent primarily on the physical or temperature conditions of the oceanic waters. When carbonate of lime is precipitated by alkaline solutions, such as carbonate of soda, carbonate of ammonia, or carbonate of methylamine, the effect of temperature is very marked, and it appears to be the case that the secretion of carbonate of lime by organisms is of the nature of a fine precipitation in the interior of the soft structures.[6] If we add sufficient carbonate of ammonia to sea water at different temperatures to convert all the

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[5] Natural Science, vol. ii, 1897, pp. 25-27.

[6] Murray and Irvine: Proc. Roy. Soc. Edin., vol. xvii, 1890, pp. 79-109.

lime salts present into carbonate, we obtain a precipitate which varies both in its crystalline form, in amount, and in time of formation. At 32 degrees Fahrenheit the precipitate begins to form in about six hours as small but distinct crystals of calcite, the quantity in twenty hours amounting only to 0.2 gramme from a litre of water. At a temperature of about 47 degrees Fahrenheit a mixture of calcite and aragonite is precipitated; at 80 degrees to 90 degrees Fahrenheit the quantity precipitated is about 0.6 gramme; the precipitate begins to form in from a half to one hour, and it appears to consist of minute crystals of aragonite. It thus seems evident that carbonate of lime would be more easily and more rapidly secreted in the high temperatures of the tropics by means of the effete products of the organism."

MOTION OF THE WATER

The adaptations of shallow-water corals to their respective habitats are various. Although this subject has received more or less attention since the days of Darwin, there is still some divergence of opinion. Areas swept by strong, continuous currents are not favorable for the growth of corals, as the free-swimming planulæ have no opportunity to affix themselves. Some species grow best where they are protected from the ocean breakers; others thrive best in the region of the breakers or just below the level of their pounding. For vigorous growth, the water needs to be agitated and changed—that is, there must be circulation that will continually supply fresh water.

CHARACTER OF BOTTOM

The bottom must be firm or must be overlain by masses of rock, so as to supply suitable conditions for the attachment of settling coral larvæ, and the waters must be relatively free from silt, as deposits of such material will bury the young corals and in considerable quantities will smother older specimens.

COMPOSITION OF THE OCEANIC SALTS

There is no noticeable difference in the composition of the oceanic salts in coral-reef regions from that in other regions of the ocean. The following data are taken from F. W. Clarke's "The data of geochemistry," pages 94-95:

Mean of Seventy-seven Analyses of Ocean Water from many Localities, collected by the Challenger Expedition

W. Dittmar, analyst. *Challenger* Report, Physics and Chemistry, vol. 1, 1884, p. 203. Salinity, 3.301 to 3.737 per cent.

Cl	55.292
Br	.188
SO_4	7.692
CO_3	.207

Na	30.593
K	1.106
Rb	......
Ca	1.197
Mg	3.725
Fe, SiO_2, PO_4	......
Fe, NH_4, NO_3	......
Al_2O_3, Fe_2O_3, SiO_2	......
	100.000

" . . . allowing for all possible sources of divergence, the essential uniformity in composition of ocean salts is perfectly clear. The mass of the ocean is so great, and the commingling of its waters by winds and currents is so thorough, that the local changes produced by the influx of rivers are exceedingly small. The salinity may range from less than 1 to over 4 per cent, but the saline composition remains practically the same."

SPECIFIC GRAVITY OF THE WATER

The following data have been compiled from the *Challenger* reports:

Localities.	Range in specific gravity at 15° 56 C.
Atlantic Ocean:	
Bermuda to Azores	1.02686 to 1.02715
Cape Verde Islands to Saint Paul Rocks	1.02589 to 1.02706
Saint Paul Rocks to Fernando Noronha	1.02667 to 1.02699
Fernando Noronha to Bahia	1.02628 to 1.02748
Pacific Ocean:	
Tongatabu to Fiji Islands	1.02640 to 1.02659
Fiji Islands to Cape York, Australia	1.02609 to 1.02672
Meangis Islands to Admiralty Islands	1.02405 to 1.02576
Meangis Islands to Japan	1.02564 to 1.02570
Admiralty Islands to Japan	1.02571 to 1.02580
Sandwich Islands to Tahiti	1.02587 to 1.02696
Tahiti to Valparaiso	1.02714 to 1.02519

The total range is from 1.02405 to 1.02748, or .003.

To summarize the data on conditions under which modern coral reefs are formed: (*a*) *depth,* maximum, 25 fathoms, light strong; (*b*) *temperature,* annual minimum, 68 degrees Fahrenheit; annual mean, above 70 degrees Fahrenheit; (*c*) *water,* agitated and circulating; (*d*) *bottom,* firm or rocky, without silty deposits; (*e*) *composition of the oceanic salts,* as for the oceanic waters as a whole; (*f*) *specific gravity,* as for the ocean in general, range 1.02405 to 1.02748. Of these conditions shallow water, strong light, high temperature, circulating water, a comparatively clean sea-floor, and a chemical composition of the water insuring a supply of calcium salts for the formation of the skeletons are essential.

Paleozoic Coral Reefs[7]

IN GENERAL

The following sketch of Paleozoic reefs is very general, and is intended merely to indicate their wide stratigraphic and geographic distribution, at the same time mentioning a few of the more abundant types and facies of reef-forming organisms.

CAMBRIAN

North America.—In the lower Cambrian the *Archæocyathinæ* form banks of reef-like character in Newfoundland, California, and Nevada. There are, in a zone comprising a part of the upper Cambrian and the lower part of the Calciferous in New York, Pennsylvania, Virginia, Tennessee, Missouri, Wyoming, and Alaska, reefs predominantly composed of *Cryptozoon.*

Other lands.—Outside of North America the *Archæocyathinæ* are found in Sardinia, Spain, northern Scotland, northern Siberia, and Australia.

ORDOVICIAN

North America.—Reefs of *Cryptozoon minnesotensis* occur in the lower part of the Canadian group, in Vermont, New York, Alabama, Arkansas, and Minnesota. In the Chazy group reefs are formed by *Stromatocerium* and *Stylaræa* in New York, Tennessee, Kentucky, and Oklahoma; in the Black River, by *Stromatocerium, Columnaria, Tetradium,* and *Halysites* in Canada, New York, along the Appalachian Valley to Alabama, in Kentucky, Tennessee, Missouri, Wisconsin, and Minnesota; in the Trenton group, by *Stromatocerium, Columnaria,* and *Tetradium* in Tennessee and Kentucky; in the Cincinnatian, by *Stromatocerium, Columnaria,* and *Tetradium* in Tennessee and south central Kentucky. In the Richmond group there are reefs composed of *Stromatocerium, Columnaria, Tetradium, Beatricia, Labechia, Calapœcia, Favosites, Halysites,* and *Heliolites* in Baffin Land, Anticosti, northern Michigan, Illinois, Indiana, Kentucky, Tennessee, Texas, Oklahoma, Arkansas, Missouri, Colorado, Nevada, Wyoming, and Alaska.

SILURIAN

North America.—In the Niagaran group reefs are formed by Stromatoporoids, *Favosites, Halysites, Heliolites, Lyellia, Zaphrentis,* and *Cyatho-*

[7] This account of Paleozoic coral reefs is based mostly on oral information received from Mr. E. O. Ulrich, Frech's "Ueber Korallenriffe und ihrem Anteil an dem Aufbau der Erdrinde," Himmel und Erde., Bd. 9, 1897, p. 97 et seq.; Zittel, Traité de Pal. t, i; Geikie's "Text-book of geology;" Dana's "Manual of geology," and Grabau's "Paleozoic coral reefs," Bull. Geol. Soc. America, vol. 14, 1903, pp. 337-352.

phyllum in Wisconsin, Indiana, Ohio, Illinois, Kentucky, western Tennessee, Iowa, and British Columbia; in the Cayugan, reefs are locally formed by Stromatoporoids, *Favosites,* and *Halysites* in New York and in the Appalachian Valley in Pennsylvania, Maryland, Virginia, and Tennessee.

Europe.—Silurian reefs are reported in the Bala, upper Llandovery, and Wenlock groups of Great Britain, and in Norway, Gotland, the Baltic provinces of Russia, and Bohemia.

DEVONIAN

North America.—The Helderberg group contains reefs composed of Stromatoporoids, *Favosites, Halysites,* and a few *Rugosa* in New York, in the Appalachian Valley in Pennsylvania, Maryland, Virginia, West Virginia, eastern Tennessee, and Oklahoma; the Onondaga, reefs of Stromatoporoids, *Favosites, Michelinia, Cyathophyllum, Zaphrentis, Phillipsastræa, Acervularia, Cystiphyllum,* etcetera, at the southern end of Hudson Bay, in New York, Pennsylvania, Virginia, Indiana, Kentucky, and Minnesota; the Hamilton, reefs of Stromatoporoids, *Favosites, Michelinia,* and Cyathophylloids and other Rugosa in Ontario, New York, and Michigan. The upper Devonian reefs are composed of Stromatoporoids, *Michelinia,* and *Pachyphyllum* (the earlier rugose types of corals have become rare) in Iowa, Missouri, and Illinois.

Europe.—Devonian coral reefs are found in Devon, Boulogne sur Mer, Eifel, Ardennes, Belgium, Cologne, Elbingerode in the Harz, and the Karnish Alps.

CARBONIFEROUS

North America.—There are no known reefs, properly speaking, in the Mississippian. In the Tennesseean, reefs composed of *Michelinia, Lonsdaleia, Lithostrotion, Zaphrentis,* etcetera, occur in Indiana, southern Illinois, Kentucky, Tennessee, and Alabama; in the Pennsylvanian, *Chætetes* and the rugose *Campophyllum* form reefs in the region from Texas to Kansas, and sporadically elsewhere.

Europe.—The carboniferous limestones of Ireland, Scotland, Belgium, and central Russia contain reefs composed of Rugosa, *Zaphrentis, Amplexus, Diphyphyllum, Clisiophyllum, Lithostrotion, Strephodes,* and *Columnaria;* also *Favosites, Syringopora,* and *Chætetes.*

A review of the reef-forming Cœlenterata of the Paleozoic formations shows that beginning with the Ozarkian group of the Cambrian the same large groups that are at present active reef-builders were then abundantly represented.

The *Archæocyathinæ* of the lower Cambrian were simple corals, and, although sufficiently abundant to form beds predominantly composed of

their remains, did not possess the massive facies of the typical reef-builders; it may, therefore, be unsafe to make from biologic data a deduction applying to them. But some information is furnished by the nature of the sediments in which they are embedded. Walcott[8] gives the following localities for the species: Silver Peak, Nevada; Straits of Belle Isle, Labrador, and conglomerate limestone east of Troy and Schoolhouse No. 8, Washington County, New York. In the Silver Peak section the *Archæocyathinæ* occur in a limestone and silico-argillaceous shale in association with *Olenellus gilberti;* in the Straits of Belle Isle, in gray, reddish, and greenish limestones, there occur the characteristic coral-reef limestones varying in thickness from 25 to 50 feet; east of Troy, New York, in a brecciated limestone showing evidences of wear in most instances. Walcott says:

"The arenaceous beds (with ripple marks and trails) of the western Nevada-California area and the interformational conglomerates of eastern New York proves the presence in both areas of relatively shallow water."[9]

We can therefore safely say that some *Archæocyathinæ* lived in shoal water, and, as they formed considerable accumulations of calcium carbonate, they probably lived in a warm sea. Regarding the oceanic temperature of the Lower Cambrian, Walcott says, in the article already cited:

"That more or less uniform and favorable, even warm, climatic conditions must be appealed to in explanation of the widespread occurrence of almost identical coral-like organisms in the Lower Cambrian and of the vast number of individuals of various species of trilobites, etcetera, in Middle Cambrian time."

In the Upper Cambrian the Stromatoporoid *Cryptozoon* obtained a great development, and continued into the basal Ordovician. This Hydrozoan formed spherical masses from 1 to 2 feet in diameter, or formed greatly expanded plates a foot or more thick and from 5 to 100 feet in horizontal extent.

The Rugosa are represented in the Middle Ordovician by *Columnaria;* the Alcyonaria, represented by *Halysites, Heliolites,* etcetera, soon appear, and the great coral reef-builders of Paleozoic time were initiated. These reefs are formed by the Hydroids, *Stromatocerium, Stromatopora, Beatricia, Labechia,* etcetera; the Alcyonarian, *Halysites, Heliopora,* etcetera; *Favosites* and its allies; a great profusion of Rugosa, including many genera of massive facies, as *Columnaria, Eridophyllum, Cya-*

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[8] Tenth Ann. Rept. U. S. Geol. Survey, 1890; Bull. U. S. Geol. Survey, No. 30, 1886.

[9] Outlines of geologic history, with especial reference to North America. Symposium organized by Bailey Willis, p. 35.

thophyllum, Stauria, Acervularia, Phillipsastræa, Strombodes, Pachyphyllum, etcetera, and genera usually simple, but often with large individuals, as *Zaphrentis, Streptelasma, Amplexus, Blothrophyllum, Cystiphyllum, Heliophyllum,* etcetera, and *Chætetes.*

On the reefs of the present day the Hydroids are represented by *Millepora;* the Alcyonaria by *Heliopora* and *Tubipora,* and the Madreporaria by the composite group of coral designated the Hexacoralla. The same groups of reef-building organisms are represented in both the Paleozoic and Recent seas; in both they have the same facies as regards growth-form; in both their physiologic activity has resulted in the secretion of large quantities of carbonate from the surrounding sea-water, and in both submarine banks, known as coral reefs, have resulted. The general similarity of the organisms and the similarity in the result of their physiologic activity assuredly suggest similarity of conditions under which the physiologic process took place.

Certain Paleozoic reefs have been described in sufficient detail to give additional information on the conditions under which they were formed. Regarding the Silurian reefs of Gotland, we know that "on the flanks of the reefs are found conglomerates and breccias of coral masses, such as *Halysites* and *Cystiphyllum,* and crinoidal remains."[10] The matrix of the Silurian reef exposed in Anschütz' quarry, Cedarburg, Wisconsin, "has the structure of a sandstone, by which name it is familiarly known."

Grabau furnishes the following information on the Devonian reefs of Wisconsin and New York:

"The reefs in the vicinity of Alpena [Michigan] are best exposed in the quarries opened in the Alpena limestone, which has a thickness of about 35 feet and is the middle member of the Hamilton or Traverse group in the Thunder Bay region. Reefs occur in higher and, to some extent, in lower strata of the group, but none of these are well exposed.

"In outline the reef is roughly dome-shaped, with slopes sometimes as great as 30 or 40 degrees. The height of the dome is equal to the thickness of the limestone stratum—about 35 feet in this region—and the greatest diameter, which is near the base, is perhaps several hundred feet. The chief reef-builders represented are *Favosites, Acervularia,* and *Stromatopora,* which form the main mass of the reef, while between them are found the smaller corals and bryozoa, as well as brachiopods, crinoids, and a few other types of organisms. There is an absence of stratification in the central reef mass, the structure being exceedingly irregular. Between the corals and shells is found a filling of coral sand, which generally consists of rather coarse fragments with a predominance of crinoid joints. Solution and recrystallization have not infrequently taken place, with the result that dog-tooth spar is of common occurrence.

"The coral heads are generally of large size; sometimes they are over-

[10] Grabau: Bull. Geol. Soc. America, vol. 14, p. 343.

turned, but most of them appear to lie in their normal position of growth. In some places the crystalline coral sand forms most of the reef exposed, the large coral heads being scattered through the sand. The sand shows no stratification, so far as observed. The sand filling the cavities of the reef is generally much coarser than that forming the normal sediments on its flanks. In places at some distance from the center of the reef the rock consists of a breccia made up of brachiopods, bryozoa, and the small branching corals, with a plentiful interspersing of the joints of crinoid stems."

Concerning the reefs of the Traverse Bay region of Wisconsin, Grabau says:

"At intervals the section passes near enough to the reef to show the presence of numerous coral fragments. The fragments are all much worn and broken, and are embedded as boulders or pebbles in the stratified lime sands. Where they are abundant they constitute a veritable coral conglomerate (*calcirudite*), such as may be found near the borders of modern reefs. Good exposures of such conglomeratic beds are found in the quarries and shore sections east of Petoskey, where these coral pebbles (chiefly *Acervularia* and *Favosites* and the hydrocoralline *Stromatopora*) give the rock a strikingly mottled appearance. Not infrequently seams of carbonaceous material separate some of the layers of limestone, and in these plant remains are not uncommon. Within the thicker beds themselves the phenomena of contemporaneous erosion, of the wedging out of strata, and, occasionally, of cross-bedding and ripple marks, are met with. Indeed, all the phenomena seen in heavy bedded sandstones are found in these fragmental deposits."

He says, in describing the Onondaga reef of Williamsville, New York:

"The corals of the bedded limestone in the neighborhood of the reef are fragmental and may lie in almost any position. They indicate considerable wave activity around the margins of the reef."

By applying the criteria derived from the study of the conditions under which Cœlenterates may live and secrete calcium carbonate, and from the investigation of the physical characters, the bedding, and stratification of the sediments in which the coral reefs are embedded, the conclusions seem to follow:

DEPTH OF WATER AND INTENSITY OF LIGHT

An examination of the modern reef-forming corals has shown that they are effective workers only in depths less than 25 fathoms. Because of the zoologic affinity of the organisms, their similarity in growth-form, and the similarity of the result of their physiological activity, the conclusion appears justified that the reef-forming Cœlenterates of Paleozoic time lived in a depth of water similar to that in which those of Recent time live, or the Paleozoic reefs were formed in water not over 25 fathoms in depth.

An examination of the matrix in which the Paleozoic reef-forming corals are embedded gives information from another source bearing on the depth at which they grew. In the accounts of the Silurian reefs of Gotland, it is stated that "on the flanks of the reefs are found conglomerates and breccias of coral masses." The matrix of the Silurian reef exposed in Anschütz' quarry, Cedarburg, Wisconsin, has the structure of a sandstone. The spaces between the coral heads of the Devonian reef in the vicinity of Alpena, Michigan, "are filled with coral sand, which generally consists of rather coarse fragments with a predominance of crinoid joints. The sand filling the cavities of the reef is generally much coarser than that forming the normal sediments on its flanks." The Devonian reefs of the Traverse Bay region comprise "conglomeratic beds, while within the thicker beds themselves the phenomena of contemporaneous erosion, of the wedging out of strata, and, occasionally, of cross-bedding, and ripple-marks are met with. Indeed, all the phenomena seen in heavy bedded sandstones are found in these fragmental deposits." In the Onondaga reef of Williamsville, New York, "the corals of the bedded limestone in the neighborhood of the reef are fragmental and indicate considerable wave activity around the margins of the reef." From these data the conclusion is forced that the Silurian reefs of Gotland and Cedarburg, Wisconsin; the Devonian reefs of Alpena, Michigan, and Traverse Bay, Wisconsin, and the Onondaga reef of Williamsville, New York, were formed in water so shallow that they were within the influence of surface waves. An examination of the types of organisms composing these reveals that massive corals, such as *Stromatopora, Favosites, Acervularia*, etcetera, are important. Professor Schuchert informs me that he has seen in the Devonian reefs at Louisville, Kentucky, heads of *Cyathophyllum* "probably not less than 8 feet across," and near Alpena, Michigan, *Stromatopora* heads "that were certainly not less than 12 feet in diameter." As the reef-building organisms of Paleozoic time consist of *Stromatopora* and its allies, of *Favosites*, of masses of Alcyonarians, as *Halysites*, and massive Rugosa, the opinion seems justified that all Paleozoic reefs were formed in very shallow water, as it is probable that closely related organisms of the same facies lived under similar conditions.

The application of both the criteria derived from a study of Recent coral reefs and from a study of the sediments in which the Paleozoic coral reefs are inclosed leads to the same conclusion, which is, that Paleozoic coral reefs were formed in shallow water, often or usually at a depth not greater than that of the possibility of wave action. It seems that 25 fathoms may be considered a safe maximum of the depth for their formation.

The intensity of the light on the Paleozoic reefs is a corollary of the depth. Sunlight can penetrate beyond 25 fathoms in depth; therefore the Paleozoic reef corals lived within the region of strong light; and the opinion is ventured that the intensity of the light was a controlling factor in limiting the distribution of these organisms in Paleozoic time, as it is at present.

TEMPERATURE

In summarizing the data on the conditions in which modern reefs are formed, it was stated that the annual minimum temperature must not be below 68 degrees Fahrenheit and that the annual mean temperature must be above 70 degrees Fahrenheit. In the quotation given from Sir John Murray on the influence of temperature on the secretion of calcium carbonate by marine organisms is the statement:

> "It thus appears that the most favorable conditions for lime-secreting organisms are met with in the warm, equable tropical waters of the ocean, and here, as a matter of fact, we find the greatest development of corals and the largest number of lime-secreting pelagic organisms. In the polar areas and in the cold water of the deep sea there is, as is well known, a feeble development of all carbonate of lime structures in marine organisms."

A high temperature is necessary for vigorous organic metabolism and facilitates the secretion of carbonate of lime. The size of some of the Paleozoic coral heads indicates how vigorous was this secretion by the Paleozoic zoophytes. From an examination of modern reefs and a study of the conditions favorable for the organic secretion of large masses of the carbonate of lime, the deduction seems safe that the Paleozoic coral reefs were formed in water of rather high temperature, the annual minimum not being lower than a temperature between 60 and 70 degrees Fahrenheit; and the annual mean, probably above 70 degrees Fahrenheit.

MOVEMENT OF OCEANIC WATERS

That the waters surrounding the Paleozoic reefs were in motion, not stagnant, needs only brief discussion. That the waters were agitated is indicated by the coarseness of the sediments on some of the reefs and by such phenomena as ripple-marking.

CHARACTER OF THE BOTTOM

For modern reefs a comparatively clean and rather firm bottom is necessary for the growth of zoophytes. The organisms need proper basal support, and the accumulation of fine sediment is fatal to them. We may be confident that similar conditions were necessary in Paleozoic time.

COMPOSITION OF THE OCEANIC SALTS

An opinion on the composition of the oceanic salts in the Paleozoic era can not be based on any very definite evidence, but there seems no

special reason, perhaps, excepting very early stages in the earth's history, why the composition of the salts in solution in the ocean should have varied from one geologic age to another. Because of the lithologic similarity of material in suspension laid down as sediments in the oceans from Paleozoic to Recent time, it appears probable that the material in solution was also similar throughout the geologic ages. The marine organisms of the earlier geologic ages, although different from those of the later, represent the same zoologic groups, and their skeletons indicate the extraction of salts from the medium in which the animals lived by similar physiologic processes. The available evidence indicates that the oceanic salts in Paleozoic time were not essentially different from those of the ocean of today.

SPECIFIC GRAVITY

There are no means of directly obtaining light on the specific gravity of the oceanic waters in Paleozoic time, but we may reach an opinion on the subject through inference. The specific gravity of ocean water is determined by the quantity of salts in solution, and of these the calcium salts are important. As the Paleozoic lime-secreting organisms required calcium salts to be in solution in the medium in which they lived, a specific gravity of the oceanic water considerably above that of pure water was necessary. Although a quantitative estimate can not be given of the specific gravity of Paleozoic oceanic waters, it may be stated that salts were contained in solution, calcium salts were important constituents, and it appears probable that there has been no great variation in the specific gravity of the water of the ocean since that time.

SUMMARY

All the data obtainable from various sources indicate that the Paleozoic coral reefs were formed under conditions similar to those under which Recent reef corals live.[11]

The conclusions may be summarized as follows:

(*a*) Depth, maximum, 25 fathoms; light, strong.

(*b*) Temperature, annual minimum not lower than between 60 and 70 degrees Fahrenheit and probably above 70 degrees Fahrenheit.

(*c*) Water, agitated and circulating.

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[11] Bonney says in his appendix to Darwin's "Structure and distribution of coral reefs," p. 331: "Moreover, the *aporosa* and *madreporaria*, which are now the chief reef-builders, have only become common since the conclusion of Paleozoic ages, so that the largest volume of the gelogical history of the earth is excluded from consideration, because in the time which it covers the habits of the reef-builders may have been different." The evidence here presented shows, in my opinion, that the habits of reef-building corals have always been similar.

(*d*) Bottom, clean or relatively free from deposits of silt.

(*e*) Composition of the oceanic salts, probably the same as in the ocean of the present day.

(*f*) Specific gravity of the oceanic waters, probably about as in the ocean of today. Certainly the specific gravity was high enough to furnish the large quantities of calcium salts demanded by the reef organisms for the formation of their skeletons.

BEARING OF THE PALEOZOIC BRYOZOA ON PALEOGEOGRAPHY[1]

BY E. O. ULRICH

The Bryozoa undoubtedly lead all other Paleozoic invertebrates except the Ostracoda in abundance of individuals, and probably also in specific differentiation. They occur more or less profusely in all kinds of deposits save in the coarser quartzose sandstones and in black shales. They seem to have preferred waters depositing slightly argillaceous limestone. Like their recent representatives, they flourished best in relatively quiet waters and at depths little beyond the zone of violent wave action. In their mature development and habits of growth they are essentially bottom-dwelling sessile organisms, their calcareous colonies being attached to stones, dead shells, and other foreign objects. It is for this reason that they are absent or rarely found in black shales, in which littoral, and in fact bottom-dwelling invertebrates of all sorts, are similarly infrequent. Although usually fixed in their mature stages of growth, their larval forms are free-swimming, and this fact, doubtless, accounts for the great geographic distribution often attained by species of this class. It also suggests that their dispersal, which was greatly facilitated by currents, took place rapidly, and in this lies their great value as horizon markers. In fact no other group of organisms has proved of greater value in stratigraphic correlation.

In general aspect bryozoan colonies vary exceedingly. Some form masses several feet in diameter and grow so profusely as to almost rival the corals in reef-building. Some are hemispheric, others twiglike or bushy, but more of them, especially of the middle and late Paleozoic species, form very delicate lacelike fronds or incrustations.

The Bryozoa seem to have originated in the Caribbean Sea or Gulf of Mexico, the oldest representative being a species of Nicholsonella, found in Canadian rocks in northern Arkansas, laid down by waters invading

[1] Manuscript received by the Secretary of the Society May 23, 1911.

the Mississippian embayment. The prevailing types in the Ordovician, in which deposits they for the first time attain any considerable abundance, belong to the solid massive forms known as the Trepostomata. Beginning with the Silurian, the lacelike Fenestellidæ, a large family of the Cryptostomata, become by far the most abundant representatives of the class. The bifoliate Cryptostomata began early in the Ordovician and continued practically to the close of the Paleozoic, while the Cyclostomata, which are likewise old, continue to the present. The Trepostomata, including mainly massive and branching colonies, have been of the greatest service in stratigraphic correlation. This is, first, because of their great abundance and widespread distribution, and, second, because of the certainty and relative ease with which the species can be positively determined by means of thin-sections. Even small imperfect specimens can be determined beyond doubt. The bifoliate Cryptostomata are of nearly equal service, but in these the shape and surface characters are of more importance, requiring greater perfection in preservation to insure positive determination. As to the Fenestellidæ and other delicate types, whose discrimination depends solely on easily effaced surface characteristics, these are of correspondingly less practical value for stratigraphic purposes. However, at their worst, a long experience among the Paleozoic fossils has shown that the Bryozoa compare favorably as guide fossils with any other class of organisms.

Considered in their paleogeographic bearings, the abundance of the Bryozoa and their occurrence in nearly all kinds of deposits may be said to establish the prevailing shallowness of the continental seas in which they flourished, while a comparative study of the species shows differences in geographic distribution which can be attributed only to localization of origin and development and dependence on currents for their transportation. In some cases many genera are represented only in faunas which can be traced to invasions of a particular sea. The latter is of especial importance in paleogeography, in that their abrupt geographic limitation suggests considerable detail in the pattern of the continental seas and lands. For example, regarding certain clearly discriminated faunas found in sediments that wedge out northwardly by overlap, we may be certain that they invaded through some opening in the south. Further, we may infer that the origin and dispersal of the fauna lies in one of the permanent oceanic basins in that direction. On the other hand, if beds and faunas extend and terminate in a similar manner in a southward direction, the sea in which the fauna originated and developed is for like reasons located to the north. We then have introduced into the

geographic pattern of some particular time period continental basins connecting in the case of North America with the Arctic on the north, the Atlantic and Pacific on the east and west, and still others that were occupied by waters invading from the Gulf of Mexico.

Possibly these different oceanic waters contributed to continental basins at the same time, but as a rule this would seem to be highly improbable. Instead it is thought that when seas were entering the southern border and filling certain continental basins the northern waters were excluded. Whether solely by tilting of the surface of the continent, or whether abundant heaping of oceanic waters toward the equator and then back to the poles contributed in any marked degree, is not readily determinable and is, after all, beyond the scope of the present paper. Under this conception it follows that the same basin often contains superposed deposits and faunas originating in the Arctic, the Atlantic, and the Gulf of Mexico, and occasionally, as in Oklahoma, in waters from all four sides.

The Paleozoic basins now included within the Mississippi Valley usually alternated between the Gulf of Mexico and Arctic waters, but these, so far as known, were never present at the same time and therefore never mingled. In the Appalachian region, however, where Gulf and, more rarely, Arctic waters alternate with Atlantic invasions, confluence of the first and last and consequent mingling of the faunas is occasionally suggested.

However, even in these instances the community of species in otherwise typical north Atlantic and Gulf faunas may be more plausibly explained on the assumption that these species ranged in the south Atlantic as well as the north Atlantic, hence invaded from both directions. Therefore, without going into a detailed statement of the facts on which the opinion is based, it is concluded that the several oceanic waters and faunas seldom if ever intermingled within continental basins.

As said, the Bryozoa began to constitute a very considerable proportion of the marine faunas of the continental seas in the middle Stones River, a group of Ordovician rocks that is well developed in central Tennessee and attains much greater thickness in the Appalachian Valley. The Bryozoa are especially abundant in the Pierce division of the group, a bed with a maximum thickness of 27 feet in central Tennessee, but attaining much greater dimensions in the southern Appalachians. The Bryozoa characterizing the Pierce consist chiefly of bifoliate Cryptostomata belonging to the Ptilodictyonidæ and Rhinidictyonidæ. In central Tennessee, also in the southern Appalachians in Alabama and eastern Tennessee, these forms are exceedingly abundant, but in following the beds northward in the Appalachian Valley they rapidly diminish in num-

ber until they are practically absent throughout the corresponding part of the formation in Virginia, West Virginia, and Pennsylvania. Whatever reason may be assigned for this northward diminution, the fact remains that they are abundant in the south. Hence the inference is plain that they must have been derived from that direction—in other words, from the Gulf of Mexico and perhaps other contributory seas lying beyond it. Other evidence tending to the same conclusion is that very similar species of Bryozoa, about whose derivation from the preceding Pierce fauna there can be no question, occur in the Lebanon, an upper Stones River formation, and again in the Lowville, the first of the deposits of the Black River group. The Lebanon Bryozoa, like those of the Pierce, diminish rapidly northward in the Appalachian Valley; the Lowville much more slowly, so that a very fair representation of the Tennessee species of this formation is recognizable as far north as New York and Canada. From this point westward to Minnesota they rapidly diminish in number. Following the Lowville southward from Minnesota we find that the Bryozoa, like the corals, are almost entirely absent.

The three invasions of Bryozoa so far mentioned are undoubtedly from the south. Doubtless the distribution of these organisms in the continental basins was favored by warm currents entering the inland seas from the oceanic basins contributing the water. As previously stated, the migration of the Bryozoa is largely confined to this mode of dispersal. Considering the limited geographic distribution of the Pierce and Lebanon Bryozoa, the invading currents must have been of relatively small importance in those seas. Physical data bearing out this view are at hand. The wider distribution of the Lowville types suggests perhaps more active and certainly longer sustained currents.

That these currents passed up chiefly along the east shore of their respective seas is likewise suggested by the distribution of the Bryozoa. So far as known, Bryozoa are entirely absent in the Stones River rocks of northern Arkansas and Missouri, and either very rare or totally absent along the western, northern, and eastern shores of the basin as far as southern Virginia. As stated, the Bryozoa are also very abundant in the Lowville, and that here again their number becomes less and less away from the southeastern shore until in Missouri but a single species remains, and this owes its presence to its parasitic habit on a shell whose migration was less dependent on currents.

Similar conditions of migration by currents is suggested by the Bryozoa and corals of late Paleozoic ages. It is especially well marked by the Onondaga Bryozoa, which are abundant all along the eastern shore up to Ontario, but are almost entirely wanting on the flanks of the Ozark up-

lift, which form a part of the western shore. The significance of such facts are apparent when we note the relatively short distance separating Missouri and southern Illinois from the Nashville and Cincinnati domes, and the much greater distance between western Tennessee and Ontario, along which the deposits of this age are filled with Bryozoa and corals.

From the facts just stated it is inferred that a marine current entered from the Gulf and, hugging the eastern shore, carried the free-swimming larvæ of these sessile types as far as it was competent. In the case of the Stones River this current seems to have spent its force before reaching Virginia. In the other two cases, the Lowville and Onondaga, the current continued on through New York and Ontario.

More or less similar invasions of southeastern American continental basins occurred in succeeding Paleozoic ages. Notable among them is the early Trenton Wilmore limestone fauna, which contains a number of Bryozoa ranging from Kentucky to Canada; second, the late Eden and Maysville faunas, which contain numerous forms in zones which can be followed up the Appalachian Valley from Tennessee to New York and southern Ontario, where they are represented in the Lorraine formation; and, third, the late Clinton Rochester shale, which has a similar distribution. A somewhat different distribution of bryozoan faunas invading from the south is shown by the earliest Clinton, which extends, like the Lorraine preceding it, from Tennessee to southern Canada in a northeasterly direction, but also extends to Oklahoma in a western direction. The Helderbergian fauna, which includes many Bryozoa, is a good example of a southern Atlantic fauna invading separate continental basins, in the one case through the Mississippi embayment, and in the other from the middle Atlantic to the Appalachian troughs by way of an inferred opening at Chesapeake Bay.

Finally, the late Tennessean Chester Bryozoa, which passed northward in and across the Atlantic to England, where they are represented in the Mountain limestone, and which, on the American side, spread through the continental basins of southeastern United States from northern Arkansas to Maryland.

The invasions from the north—that is, from the Arctic basin—are similarly and no less readily discriminated than are the southern invasions. Like them, the faunas range as far south as their respective beds extend, terminating their geographic distribution when these beds wedge out by overlap. There are two important Ordovician bryozoan faunas which evidently originated in the Arctic and spread southward into the basins of North America. The first of these is best known from the late

Black River or Decorah shales of Minnesota and Iowa. It has been recognized also at a number of localities in eastern British America and extends southward in the Mississippi Valley to central Kentucky and northern Tennessee. In the latter two States the fauna, which is in everywise typical, has been noted at only a few localities. Where observed the bed is only from an inch to 2 feet in thickness and is limited above and below by formations containing totally different faunas of southern origin. Further, the upper and lower boundaries of this bed exhibit clear evidence of interrupted deposition. Moreover, these extreme southern wedges of the Decorah shale seem to be entirely confined to shallow hollows in the underlying Lowville limestone. The facts are essentially similar with respect to the second of these Arctic faunas, the main difference being that whereas the first is entirely unknown, at least in the *northern* Appalachian region, the second is locally developed in central and eastern New York and extends thence southward into New Jersey. Like the first, it is best developed in southern Minnesota and northern Iowa, where it is found in the Prosser limestone, the proposed name of a formation comprising the Clitambonites, Nematopora, and Fusispira beds of the Minnesota reports. The third Arctic fauna is early Silurian in age and belongs in the Richmond series. It is marked especially by corals and Bryozoa, both of a decidedly Silurian aspect. It is known in Baffinland and Alaska, and is locally found on this continent to the south as far as southern Illinois, where it is included in the Noix oolite or Edgewood beds. In the far West it is widely distributed, being known in Arizona, Utah, New Mexico, and western Texas.

That these forms really originated in the Arctic basin is indicated not only by their distribution in North America, but also by the fact that they are similarly developed in the Baltic province of Europe. As has been clearly shown by studies of the Baltic Bryozoa just completed by R. S. Bassler, a large proportion of species described from these beds in Minnesota and elsewhere in America are represented by identical and very closely allied species in Russia. Up to date 70 out of 143 Minnesota species of this class are found also in Russia.

To sum up, the Bryozoa have an exact bearing on paleogeography (1st) because of the abundance of their fossil remains, (2d) because of the certainty and comparative ease of ascertaining the critical characters, (3d) their indication of the shallowness of the seas in which they lived, (4th) their rapid and wide dispersal, justifying conclusions respecting the essential contemporaneity of their occurrence, and (5th) the light they throw on the direction and extent of marine currents.

PALEOGEOGRAPHIC AND GEOLOGIC SIGNIFICANCE OF RECENT BRACHIOPODA[1]

BY CHARLES SCHUCHERT

CONTENTS

Number and Rank of recent Brachiopods

There is no class of living shelled animals better known as to their structure, habitat, and geographical distribution than the Brachiopoda. They have been persistently dredged for because of their rarity by many exploring vessels, in all seas and in all depths, and have been studied by many workers, chiefly in Europe, America, and Japan. A careful study of the rather diffuse literature[2] reveals 166 more or less well known

[1] Manuscript received by the Secretary of the Society May 23, 1911.

[2] The information here given has been gathered from many sources, but the more important works are as follows:

Beecher: Revision of the families of loop-bearing Brachiopoda and development of *Terebratalia obsoleta* Dall; Trans. Conn. Acad., 9, 1893.

Blochmann: Untersuchungen über den Bau der Brachiopoden, Jena, 1892 and 1900. Neue Brachiopoda d. Valdivia u. Gauss Expedition, Zool. Anzeiger, 30, 1906. Zur Systematische u. Geographische Verbreitung d. Brachiopoden, Zeit. f. Wiss. Zool., 90, 1908.

Buckman: Antarctic fossil Brachiopoda, Schwedische Südpolar-Expedition, 1910.

Dall: Many papers from 1870-1909.

Davidson: A monograph of recent Brachiopoda, Trans. Linnean Soc. London, 4, 3 parts, 1886-1888.

Hall and Clarke: An introduction to the study of Brachiopoda, Rep. N. Y. State Geol., 1894.

Schuchert: A synopsis of American fossil Brachiopoda, Bull. U. S. Geol. Surv., 87, 1897.

Yatsu: Notes on the histology of *Lingula anatina,* Jour. Coll. Sci., Imp. Univ., Tokio, 17, 1902. Habits of the Japanese Lingula, Annot. Zool. Japonenses, 4, 1902.

forms, and these are distributed in 33 genera. Of these about 8 forms are poorly defined, so that there are at least 158 established species of living brachiopods. However, with the refined methods recently introduced by Blochmann and Dall, and in the further dredging that is now going on in Antarctic waters, we may expect a considerable increase in the number of species, so that eventually there may be a total of about 180 forms. Whatever the additions may be to our knowledge, that in regard to their habitats, bathymetric and geographic range will be slight. We therefore have safe guidance in the living members of the class as to what the bathymetric range and habitats of the fossil forms were.

The 158 living forms are grouped according to their relationship as follows: Of Inarticulata there are 29 and of Articulata 129. The inarticulate brachiopods are nearly equally distributed among the orders Atremata (15) and Neotremata (14), there being of lingulids 15, discinids 7, and of Crania 7. Of the once wonderfully prolific Paleozoic order Protremata there are but 2 living representatives in Thecidium, a genus that arose in the Cretaceous. They are small forms, and though not rare in the Mediterranean and Antillean regions, are restricted to a depth ranging between 30 and 300 fathoms. Both also occur fossil since the Miocene or Pliocene, and are therefore morphologically static. The Telotremata are the dominant brachiopods, being represented by 15 rhynchonellids and 112 terebratulids, and of these the last named had far less differentiation in the Paleozoic. Both stocks are very ancient, the rhynchonellids being as old as the Middle Ordovicic and the terebratulids arising early in the Devonic. While neither stock was prolific in genera and species throughout the Paleozoic, both stocks began to evolute in the late Triassic, and in the Upper Jurassic the seas swarmed with a great variety of these animals, and especially of the terebratulids. The decline of the latter began in the Cretaceous and persisted to the Oligocene, when the warm waters of this time seem to have rejuvenated the stock to its present good representation. On the other hand, the rhynchonellids have maintained their generic and specific variation fairly constant since the Siluric, when for the first time the stock was well established. In the Jurassic, however, they were more abundant than at any other time. We learn, therefore, that though these two stocks are very old, they are still morphologically young and plastic, constantly giving rise to new forms and new genera.

Bathymetric Range

In General

The bathymetric range of the 158 species is as follows:

Five, or 3 per cent, are restricted to the strand-line (3 Inarticulata, 2 Articulata).

Forty-four, or 28 per cent, range from the strand to about 90 feet (21 Inarticulata, 23 Articulata).

Sixty-three, or 40 per cent, range from 90 to 600 feet (7 Inarticulata, 56 Articulata).

From the strand to 600 feet occur nearly 71 per cent of the living brachiopods, or 112 forms.

Seventeen, or 10 per cent, range from 600 to 1,000 feet (all Articulata).

Eleven, or 7 per cent, are deep-water forms below 1,000 feet, but adjacent to continents (all Articulata).

Eighteen, or 11 per cent, are deep-sea forms situated near continents (1 Inarticulata, 17 Articulata).

Of typical deep-sea mid-oceanic forms ranging from 200 to 2,465 fathoms there are 5.

Of the 158 recent species, at least 10 are practically restricted to the area between tides. These are *Laqueus* (?) *aleuticus*, *Magellania flavescens* (goes down to 14 fathoms), *Megerlina davidsoni* (in an extinct volcanic crater), *M. lamarckiana* (goes in deeper water), an uncertain species of *Terebratalia* (?) *radiata*, *Lingula anatina* (there are probably other species of this genus), *Discina striata*, *Discinisca cumingi* (down to 8 fathoms), *D. lamellosa* (to 10), and *D. strigata*.

Between low-water mark and above 90 feet of depth the great majority of inarticulate brachiopods live, or 21 species out of a total of 29 (Lingula, 11; Glottidia, 4; Discina, 1; Discinisca, 4; and Crania, 1). Of the articulate brachiopods, 23 out of the 129 live in these shallow waters, and of those but 7 continue their range below 100 fathoms (Bouchardia, 1; Dallina, 1; Dyscolia, 1—goes down to 250 fathoms; Frenulina, 1; Gwynia, 1—goes down to 2,000; Kraussina, 1; Laqueus, 3; Liothyrina, 1 down to 600, 1 down to 1,300; Macandrevia, 1 down to 1,400; Terebratalia, 1; Terebratella, 6—1 down to 120, and Terebratulina, 4—1 down to 1,170).

From 90 feet and down to 600 feet there appear (with one exception) all the remaining species of inarticulate brachiopods, 7 in number (Discinisca, 1; Crania, 6). Of the articulate forms, 56 appear here for the first time, and of these at least 23 continue into still deeper water (Agul-

hasia, 1; Cistella, 6; Cryptopora, 2; Dallina, 3; Hemithyris, 6; Laqueus, 4; Liothyrina, 6; Magellania, 4; Megathyris, 3; Mühlfeldtia, 3; Platidia, 2; Terebratalia, 4; Terebratella, 3; Terebratulina, 7, and Thecidium, 2).

Below 600 feet and above 1,000 feet appear 17 additional articulate species (Acanthothyris, 1; Cistella, 3; Dallina, 2; Hemithyris, 1; Kraussina, 4; Liothyrina, 2; Macandrevia, 2; Platidia, 1, and Terebratulina, 1).

There are 11 deep-water forms, not one of which extends above 1,000 feet of depth or goes into the abyss. As a rule they are, like the abyssal forms, thin-shelled animals, but do not average as small as the true deep-sea species. These are the rhynchonellids *Hemithyris gerlachi* (243-270 fathoms), *H. racovitzæ* (270), and *Basiliola beecheri* (200-313), occurring off western Hawaii; the terebratulids, *Dyscolia wyvillii* (385-845), *Liothyrina antarctica* (385), *L. sphenoidea* (215-1,090), *L. subquadrata* (500-600), *L. winteri* (360), *Mühlfeldtia echinata* (346-423), *Platidia* (?) *incerta* (390-1,120), and *Terebratulina valdiviæ* (392).

Of typical abyssal forms that have strayed far from the continents there are but five: the discinid *Pelagodiscus atlanticus* (200-2,465); the rhynchonellid *Hemithyris strebli* (2,035-2,084); the terebratulids *Chlidonophora chuni* (865-1,220); *C. incerta* (292-1,850), and *Liothyrina* (?) *wyvillii* (1,035-2,900). To these must be added 13 other forms that are also abyssal in habitat, but are still situated close to the continents. These are the rhynchonellids *Hemithyris craneana* (1,175); the terebratulids *Frieleia halli* (599-984), *Eucalathis* (the 4 species of this genus, 300-2,588), *Liothyrina clarkeana* (1,175-2,035), *L. mosleyi* (210-2,222), *Macandrevia craniella* (1,175), *M. diamantina* (1,175-2,222), *M. tenera* (1,450), *Magellania wyvillii* (2,160), and *Terebratulina* (?) *dalli* (1,875). All of these abyssal species are small in size or below the average of their genera, and have very thin, fragile shells.

These figures giving the bathymetric range of recent brachiopods teach us that fully 80 per cent inhabit waters shallower than 1,000 feet, and over 70 per cent live above 600 feet. Brachiopods therefore are, as a rule, significant of shallow water and of continental or epicontinental seas.

INARCTICULATA GENERA

Let us now examine into the detailed bathymetric range of the 33 living brachiopod genera, to see if anything can be learned from their distribution that will give guidance as to the depths at which the fossil forms lived. We have seen that but 5 species are restricted to the strand-

line, but that in water less than 90 feet deep there occur about 49, or 31 per cent, of all living brachiopods. The most conspicuous of these shallow-water forms are of Lingula and Discina, genera that are restricted to the littoral region—that is, ranging from the strand-line to a depth of probably not much more than 60 feet. In addition to this, many of the species of lingulids occur in bays and estuaries, indicating that they prefer a habitat more or less freshened by land waters. Discinisca also lives in the littoral region, but apparently never on the strand-line, and no species goes beyond 216 feet of depth. Glottidia commences at lowest tide, and has been taken as far down as 360 feet. Crania is not reported from the tide-line, but begins in 12 feet of water, and extends its bathymetric range to 808 fathoms. Of all the living inarticulate brachiopods, but one is completely habituated to deep water—*Pelagodiscus atlanticus*—which has a range from 200 to 2,425 fathoms. It is also a cold-water species, and its geographic range appears to be now or to have been world-wide, for it is known in the north and medial Atlantic Ocean, the Pacific, and off Australia. In its arm structure it is also very primitive, in that the brachia are not spirally rolled, but "form two simple loops, with no spirals whatever" (Dall, 1907). In other words, the brachia are in the schizolophus stage, as defined by Beecher,[3] and therefore do not develop into the more complicated structures seen in most living brachiopods.

A survey of the geographic distribution of the inarticulate brachiopods also shows that all the littoral and shallow-water species are bound to warm waters, and that hardly any are common to two zoological provinces. Furthermore, when the shallow-water and littoral forms are compared with those of the deeper, and especially the one species of abyssal waters, we note that the former are decidedly more prolific in numbers, are often considerably larger and always have thicker shells, while the deeper water forms are nearly always smaller and have thin and nearly transparent valves. The smallest form with the thinnest valves is the abyssal *Pelagodiscus atlanticus*.

These results are of the greatest value to the paleogeographer, for they can be successfully applied to the fossil Inarticulata, and through this knowledge one can state positively the depth of water at which the fossil lingulids and discinids lived. Further, they are excellent guides as indicators of shorelines, and as such give clear guidance to the paleogeography of any given time.

The paleontologist finds that the greatest number of large, thick

[3] Beecher: Bull. U. S. Geol. Surv., vol. 87, 1897, p. 108.

shelled specimens and the greatest variety of species of lingulids and discinids are found in shales and sandstones, and, furthermore, that the physical evidence of the deposits in which such occur is in harmony with the character of the sediments and the present distribution of the littoral and shore living inarticulates. On the other hand, it is not at all rare in the older Paleozoic deposits to find lingulids and discinids in limestones and dolomites, and when the specimens are large and thick shelled, even though they occur in such organic deposits, they give unmistakable evidence of very shallow-water conditions and a hint that the shore may not have been very far away. Small and thinner shelled species are also frequently seen in limestones and shales, but the associated animals and the character of the strata demonstrate that these also are shallow-water forms. On the other hand, in black shale deposits (Utica, Marcellus, Genesee), and more rarely in thin zones of black limestones (Marcellus, Genesee) is frequently seen an abundance of very small and even minute species of obolids, lingulids, and discinids that could not have lived on the bottom of these "Black Seas" with their carbonaceous or even sulphurous depths. Nor can their size and frailty be taken as evidence for deep-sea deposits, for they are manifestly of the surficial waters of a sargasso-like sea, where in all probability they lived attached to floating algæ. In such deposits the evidence of the associated animals is that they are either floaters (graptolites, or spore cases of algæ), or swimmers (pteropods as Styliolina, cephalopods as Endoceras, nautilids and goniatids), or commensal floaters anchored to other suspended organisms as the byssally attached thin shelled and modified bivalves described by Clarke from the Genesee of New York.

It is also desirable to point out here the wonderful vitality of the living inarticulate brachiopods. Lingula is exposed on the tidal flats of Japan for hours without injury, and on account of its accessibility is regularly gathered by the poorer people for food. At high tide these animals are covered with 3 to 4 feet of water. Their habitat may be brackish or foul with decomposing organic matter, even to such an extent that all other shell fish may be killed off, but Lingula will continue to live under such adverse conditions. Yatsu, who has studied living Lingula, tells us that on little estuaries in certain bays of southern Japan their habitats may be covered by sand and mud brought down by stream freshets, so that all of the burrowing shell fish will be destroyed, but Lingula will still live in such stinking places and the individuals tunnel themselves to the surface. The burrows are from 2 to 12 inches long, and the movements of the animals up and down in the holes are made by means of the highly contractile and regenerative peduncle. It is thought that Lingula may

attain an average age of 5 years or even more. Yatsu kept them alive in aquaria with the water fetid, and Morse did the same, keeping his specimens alive for six months in almost unchanged water. Joubin kept Crania, taken from great depths, alive in jars under very adverse conditions for 14 months. In these statements we see the very adverse conditions under which the burrowing Lingula may live, and that the tenacity of endurance is also very great with cemented Crania. In this adaptability lies the probable explanation of why the lingulids and craniids have lived since the Ordovicic. Lingula and Crania have endured all of this vast time apparently without change other than the superficial ones of form, size, and ornamentation.

We may therefore conclude that inarticulate brachiopods when large, thick shelled, and abundant clearly indicate to the paleontologist animals inhabiting very shallow waters of probably less depth than 100 feet. Further, that these waters were in close proximity to the shores and probably were warm. Crania is the only genus inhabiting shallow waters of the cooler areas and essentially those of the northern hemisphere. The immediate shoreline, and often the estuarine bays and deltas, will be indicated especially by the large lingulids embedded in muds and sands with an otherwise sparse fauna. When the species are small, but not minute, still somewhat thick shelled and the individuals abundant, it is probable that the sediments of such waters were also those of the shallows—that is, ranging between 50 and 200 feet, with the possibility of even 400 feet. Minute inarticulates are not safe guides to bathymetric depth in Paleozoic time, and their habitat significance must be judged more from the associated fossils and the character of the entombing sediments. The Atremata, after the Cambric, appear always to have preferred shallower waters near the strand-line, while the Neotremata, though also lovers of shallow waters, appear to have preferred to keep away from the immediate strand. These slightly varying habitats have their probable explanation in that all the Atremata, after the Cambric (lingulids), lived in burrows, while those of earlier times (obolids) appear to have lived above the bottom, fastened to foreign objects by a more or less long peduncle. On the other hand, the Neotremata are never burrowers, but are fastened to some object above the ground by a very short peduncle that issues directly through some part of the ventral valve, as in the highly modified bivalve Anomia. We see, therefore, that the burrowing lingulids are protected from wave action, and that their holes are always full of water, while the discinids live above the bottom, and because of their very much cramped shell space would, at low tide, be without water for hours. Further, the peduncle in Lingula and the

Atremata is a burrowing and prehensile organ, while in all other brachiopods it is for permanent attachment to a given place. It is true that some discinids do approach the strand, but as they have a more or less centrally placed short and pluglike peduncle and a conical upper valve the waves can have little effect in pulling them from their anchorages. On the other hand, in the articulate brachiopods the peduncle is more or less long and emerges from one valve, so that the animals hang loose at one end of the stalk, a decidedly disadvantageous mechanical defect for holding in tumultuous waters. It is probably for these reasons that most brachiopods avoid the tearing strand-line, and are most abundant in the quiet waters between 50 and 500 feet.

ARTICULATA GENERA

None of the articulate brachiopods can be relied on to indicate the strand-line, as but 5 approach or live in this zone, and but a single genus appears to be restricted to very shallow water (Megerlina, with its 2 species). The other 3 forms prefer deeper water. Of the 129 articulate species about 19 per cent (25 species) live in less than 90 feet of water. Their real habitat, however, is in the deeper water between 90 and 600 feet, where nearly 46 per cent (59 species) live. Down to 600 feet occur 84 articulate and 28 inarticulate forms, or, in other words, more than 70 per cent of brachiopods are at home in these shallower waters. We may, therefore, conclude that the greatest abundance of living brachiopods is in the stormless waters between 90 and about 500 feet of depth.

None of the 15 rhynchonellids live in very shallow water, nor are any reported in less than 90 feet, but as *Hemithyris psittacea* is thrown up on the Labrador coast by the storms it is probable that this form lives here not far from the strand-line. The living species are grouped in 4 genera, of which Acanthothyris, with 1 form (160 fathoms), Basiliola, with 1 form (200-313), and Cryptopora, with 2 forms (25-2,200), may be regarded as the deep-water genera. Hemithyris has 11 forms, and of these but 2 live between 90 and 288 feet, while the others range down to 2,084 fathoms. We therefore see that the rhynchonellids are now deep-water brachiopods, but this certainly was not the case during the Paleozoic, where they are frequently found in coarse sandstones, and not at all rarely in mudstones, associated with medium sized and thick shelled lingulids. Today they are found in nearly all parts of the oceans, from north of the Arctic Circle to far south in the Antarctic region. While most of the species live in cool waters, at least one (*H. cornea*) ranges from the warm water off Cape Vincent in 57 fathoms down to the cold waters off Cape Finisterre in 1,093 fathoms. *Cryptopora gnomon* has

been dredged in the warm waters off the Canaries in 50 to 65 fathoms, in the cool waters off the Azores in 2,200 fathoms, in the cold waters off Ireland at 1,443 fathoms, and in Davis Strait at 1,750 fathoms. While temperature does now somewhat restrict the geographic and bathymetric range of the rhynchonellids, still the majority seem to prefer the cooler and deeper waters. This the writer believes to be a modern adaptation that has come about since the Jurassic.

In regard to the geographic distribution, some of the species are locally restricted, others range through several provinces, and one (*H. psittacea*) is found throughout the greater part of the northern hemisphere.

The conclusion derived from the living rhynchonellids, therefore, is that they give no satisfactory guidance as to the bathymetric distribution of the fossil forms. In regard to their geographic occurrence, the Paleozoic distribution is very much like that of the living forms, and very little safe guidance is therefore to be derived from them as provincial indicators. Extinct species of the same genus may have local or very wide distribution, may be restricted to a geologic zone of but a few feet in thickness or range through the greater part of a period (Devonic), but sometimes a single species will have a limited time range and yet be distributed over the entire North American continent (*Rhynchotrema capax*).

The terebratulids are in greatest abundance specifically and numerically in the shallower waters. Five occur between the tides and 76 out of the 112 forms, or 67 per cent, live in waters less than 600 feet in depth. The largest of all living species is *Magellania venosa,* growing to 3¼ inches in length and found in abundance in Magellan Straits at depths varying from 50 to 480 feet.

SHELL CHARACTERS OF DEEP-WATER SPECIES

The 29 deep-water and abyssal species are all thin shelled, often very fragile, gray or light yellowish in color, more or less transparent and generally small in size. There are, however, large species in the greater depths, but none in the abysses. Such are *Dyscolia wyvillii* (385-845 fathoms), with a length of 2.5 inches; *Liothyrina subquadrata* (500-600), with a length of 1.1 inches, and *L. sphenoidea* (215-1,090), with a length of 1.2 inches.

Geologic History of the living Brachiopods

We will next examine into the geologic range of the 33 living genera of brachiopods. There are at least 23 having fossil representation, and

this is more than 60 per cent of the living genera. Two have lived since the Ordovicic (Lingula and Crania), 6 since the Jurassic (Acanthothyris, Eucalathis, Magellania, Megathyris, Terebratella, and Terebratulina), 4 since the Cretaceous (Agulhasia, Cistella, ?Discinisca, and Thecidium), 1 since the Miocene (Platidia), 7 since the Pliocene (Glottidia, Hemithyris, Dyscolia, Liothyrina, Macandrevia, Terebratalia, and Mühlfeldtia), and 3 since the Pleistocene (Bouchardia, Dallina, and Gwynia). Of these 23 genera 6 have not spread into water as deep as 1,000 feet, these being Agulhasia, Bouchardia, Discinisca, Lingula, Glottidia, and Megathyris. Of genera that have spread beyond this depth, but which still have their best development in waters less than 500 feet, are Gwynia, Magellania, Terebratalia, and Terebratella. The genera having fossil representation, with their best development in the present seas at depths greater than 500 feet, are Acanthothyris, Cistella, Crania, Dallina, Dyscolia, Eucalathis, Hemithyris, Liothyrina, Macandrevia, Mühlfeldtia, Platidia, Terebratulina, and Thecidium. All of these are of long enduring stocks that had their rise at least as early as the Jurassic, and if we add to these the other truly deep-sea brachiopods, also of ancient phyla, but not known to have fossil representation, such as Basiliola, Cryptopora (both rhynchonellids), Chlidonophora (primitive terebratulid), Frieleia, and Pelagodiscus (discinid), we can say that the present deep-sea forms as a rule did not begin to migrate to this habitat earlier than the middle Mesozoic, and, further, that this adaptation is still going on. The truly abyssal forms, as Basiliola, Chlidonophora, Frieleia, and Pelagodiscus, are probably of stocks even older than the middle Mesozoic, and these genera may have begun their abyssal march as early as the beginning of the Mesozoic. It is, however, a noteworthy fact that of the great multitude of Paleozoic genera not one is known to have become wholly abyssal in its habitat; on the contrary, the two oldest Paleozoic genera that are still alive have not gotten far away from the strand-line. Lingula is still restricted to the littoral and Crania, while as a rule now a deeper water genus, is by no means restricted to the abyss, although it has been taken at 818 fathoms. These observations lead to the conclusion that the oceans probably did not begin to get exceedingly deep until after the great Appalachian Revolution toward the close of the Paleozoic—that is, early in the Mesozoic—and that this deepening has been going on since then. These views are also in harmony with the conclusion attained by Walther[4] from a study of the life of the present deep seas.

[4] Walther: Origin and peopling of the deep sea, Amer. Jour. Sci. (4), vol. xxxi, 1911, pp. 55-64.

Of the 158 living brachiopods but 25, or about 16 per cent, are also found fossil. None are older than the Eocene (*Megathyris decollata*); of the Miocene there are 4 additional species (*Dallina septigera, Platidia anomioides, Terebratulina caputserpentis,* and *Thecidium mediterraneum*). From the Pliocene there are 15 (*Cistella cuneata, Crania anomala, C. turbinata, Glottidia albida, Hemithyris nigricans, H. psittacea, Liothyrina affinis, L. sphenoidea, L. vitrea, Macandrevia cranium, Mühlfeldtia echinata, M. truncata, Platidia davidsoni, Terebratella dorsata,* and *Thecidium barretti*); of the Pleistocene 5 (*Cistella cistellula, Dallina* (?) *spitzbergensis, Gwynia capsula, Magellania lenticularis,* and *Mühlfeldtia monstruosa*).

Geographic situation of recent Brachiopods

IN GENERAL

All brachiopods without exception live in marine waters, and in the main their habitats are in the shallower waters bordering the continental masses. This is very clearly brought out in the "Chart of the world showing the distribution of the Recent Brachiopoda," by Hall and Clarke (1894, chart facing page 148), and in another by Blochmann (1908, plate 40), giving the distribution of the Liothyrinæ. These maps also show that but very few species have strayed far away from the continents in the truly abyssal regions. Only 5 have permanently adapted themselves to the great oceanic areas (*Pelagodiscus atlanticus, Hemithyris strebli, Chlidonophora chuni, C. incerta,* and *Liothyrina* (?) *wyvillii*). With these should be considered 13 other forms which also inhabit great depths, but whose situation remains adjacent to the continents (see list on page 6). Then there are 11 species living permanently below 1,000 feet that may be spoken of as deep-water forms, but they are not as yet deep-sea animals, because their habitats are in connection with the continental shelves (see list on page 5). In other words, but 3 per cent of living brachiopods have permanently left the continental waters, a further 8 per cent are transitional between the abyss and the continental shelves, and an additional 7 per cent are still attached to the shallower waters of the outer parts of the continental shelves. This bathymetric distribution may be stated in still another way, namely, 81 per cent of living brachiopods are bound to the shallow waters bordering the land masses, 7 per cent are in the deeper waters of the continental shelves, 8 per cent are transitional to the oceanic areas, and 3 per cent are permanent inhabitants of the vast and cold Neptunic underworld.

The shallow waters about Japan have more brachiopods by far than any area of similar extent. Here occur 29 species in 12 genera; in other words, more than 18 per cent of recent brachiopods. In the Sea of Japan, or along the western side of the islands, there are 11 species, none of which seem to range deeper than 60 fathoms, and on the outer or Pacific side there are nearly twice as many kinds, or 20 forms, ranging all the way from shore habitats down to one at 160 fathoms. There is also one deep-sea form here at 1,875 fathoms, but at least 11 of the 20 occur in waters shallower than 100 fathoms. These Japanese species are the following:

*Brachiopods of the Sea of Japan (marked by a †) and the east coast of Japan (marked with a *)*

- † *Lingula adamsi* (7 fathoms)
- † *Lingula affinis* (0-1)
- † *Lingula anatina* (0-1), widely distributed
- † *Lingula jaspida* (7)
- * *Lingula lepidula* (10)
- * *Lingula smaragdina* (10)
- * *Crania japonica* (71)
- † *Discinisca stella* (17-26), widely distributed
- * *Acanthothyris döderlini* (160)
- * *Hemithyris lucida* (48-100)
- * *Hemithyris psittacea woodwardi* (35-48)
- * *Liothyrina davidsoni* (55)
- * *Liothyrina stearnsi*
- † *Terebratulina cumingi*
- * *Terebratulina* (?) *dalli* (1,875), deep-water form
- * *Terebratulina japonica* (48-55)
- * *Terebratulina kiiensis*, widely distributed
- * *Terebratulina stearnsii*
- * *Dyscolia crossii* (100-250) widely distributed
- † *Dallina grayi* (7-37), widely distributed
- * *Dallina mariæ* (21-55)
- * *Dallina raphaelis* (100-200)
- † *Terebratalia coreanica* (7-48)
- † *Terebratalia gouldi* (60)
- * *Laqueus blanfordi*
- * *Laqueus* (?) *frontalis*
- *† *Laqueus pictus* (23-55)
- †* *Laqueus rubellus* (1-35)
- * *Frenulina sanguinea* (48), widely distributed

DISTRIBUTION OF THE GENERA

An analysis of the 33 genera shows that they are readily grouped into 5 great brachiopod areas or regions. These combine again into a deep-sea realm and 4 shallow-water geographical regions as follows: Boreal, Austral, Oceanica, and Gondwana. Each of these brachiopod areas will be discussed separately.

DEEP-SEA REALM

There are only 3 genera restricted to deep water, the discinid Pelagodiscus (200-2,425 fathoms) and the terebratulids Chlidonophora (282-1,850) and Eucalathis (300-2,588, Jurassic). The distribution of the two former is practically cosmopolitan, while the last one is re-

stricted to Atlantic Gondwana. Into this realm (below 1,000 fathoms) also enter the shallow-water genera Cistella (20-1,622, Cretaceous), Cryptopora (25-2,200), Gwynia (8-2,200, Pleistocene), Hemithyris (15-2,084, Pliocene), Liothyrina (6-2,900, Pliocene), Macandrevia (5-2,222, Pliocene), Magellania (0-2,160, Jurassic), Terebratella (5-1,450, Jurassic), and Terebratulina (3-1,875, Jurassic).

BOREAL REGION

There are 6 genera typical of this region. Of wide distribution in northern waters is Dallina. It is best developed about Japan (3 species), and from here it probably spread into Arctic waters and along the eastern shores of the Pacific southward across Panama (previous to Upper Miocene time) into the Antillean region. In Arctic waters the genus occurs at Spitzbergen, and thence south to North Africa, but no relicts are found today in any of the Atlantic oceanic islands. Laqueus and Terebratalia, both also at home in the North Pacific, and probably as old as Dallina, did not get into the Atlantic by either the northern or Panama routes. Acanthothyris, widely distributed in the later Mesozoic, is now restricted to Japan.

Hemithyris is probably also of boreal origin where the family Rhynchonellidæ is best developed since the Siluric. The present distribution of this genus is nearly world-wide, but with peculiar and extensive geographic lacunæ due to causes not yet understood. The genus has 11 species, and of these 5 occur in boreal waters, 4 in austral, 1 in Oceanica (*H. grayi*), and 1 (*H. strebli*) is a deep-sea form occurring in mid-Pacific. Of boreal species none occur off the United States or in Antillean waters. On the Pacific side of the two Americas but a single specimen has been taken in the Gulf of Panama (*H. craneana*) at a depth of 1,175 fathoms, and another form, *Frieleia halli*, occurs from San Diego, California, to Washington. *H. psittacea* is circumpolar in its distribution, attaining Japan (var. *woodwardi;* also *H. lucida*), Unalaska to Shumagins, Gulf of St. Lawrence, Norway south to Shetlands, and fossil even to Sicily. In the northeastern Atlantic occurs the non-plicate *H. cornea*. In Antarctic waters there are 3 species, with a fourth one in the New Zealand area. These forms seem to have spread from Japan south through Oceanica, and thence by way of New Zealand into Antarctica.

AUSTRAL REGION

There are 6 genera restricted to this region. Of more or less wide distribution in southern waters are Agulhasia (off South Africa), Kraus-

sina (off South Africa and Tasmania), Bouchardia (off Rio de Janeiro and abundantly fossil in Antarctica), Magellania and Terebratella (Chile, Magellan Straits, Patagonia, Australia, New Zealand, Tasmania, Kerguelens, and Antarctica). Megerlina seems to be restricted to the Australian region. There are other genera in these waters, and these are regarded as migrants to be discussed under Gondwana. This region is faunally directly connected with Oceanica.

OCEANICA

This region is not rich in brachiopods and has 3 restricted but widely distributed genera. From the Austral region there have migrated into the Australia-New Zealand area Kraussina, Magellania, and Terebratella, but they are not known north of these land masses. Common throughout this island realm are the restricted genera Lingula (also sparingly present in the Indian Ocean), Frenulina, and Basiliola (restricted to Hawaii); the two first named genera extend their range to Japan.

GONDWANA

The remaining brachiopod genera, 14 in number, appear to owe their dispersion in the main to the former but now much broken shore of ancient Gondwana. The present Mediterranean is the remainder of the ancient and far more extensive Tethys, always more or less in connection with the North Atlantic (= Poseidon) and in early Tertiary time communicating freely with the Indian Ocean. Tethys is the boundary of the northeastern area of Gondwana, and the shore thence continued westward across the Atlantic from northwestern Africa, possibly by way of the Canary and Cape Verde Islands, to Venezuela and the Antillean region. Western Gondwana, however, was being severed by Poseidon and Nereis (North and South Atlantic) during the Cretaceous, and their union into the present Atlantic certainly took place during the early Eocene. During the Tertiary previous to the Upper Miocene there was also an open seaway between the Caribbean-Panama region, so that the northern Gondwana faunas could readily continue their march south along the western side of South America into the Antarctic realm, whose waters were then much warmer than they are now. Of these Gondwana brachiopods but few, however, got into the North Pacific. To make this immensely long and very important migration route clearer, it will be necessary to present the geographical range of the genera of this realm in detail.

Restricted to the Mediterranean-Cape Verde and Portugal-England regions there are the 3 genera Gwynia, Megathyris, and Mühlfeldtia

(may have representation in South Australia in *Megerlia* (?) *willemoesi*). In common with this region and the northwestern side of Gondwana or the Antillean-Floridian and Caribbean area are the genera Cistella, Eucalathis (1 species in the Fiji region), Platidia (has spread to Lower California, but not to South America), and Thecidium.

There are 9 other genera that must be considered in detail:

Glottidia.—This genus had its origin apparently in the Antillean region, spread north as far as North California, south to Martinique, and in the Pacific north to southern California and south to Peru. The genus is known in the Pliocene of California, and the spreading probably took place previous to the upper Miocene when the Panama land bridge, between North and South America, was established. Glottidia seems to be not older than the Tertiary.

Discinisca.—The genus is most abundant off the South American Pacific, has spread north to the Gulf of California, and is sparingly present in the Antillean region. A single species occurs from Singapore to Japan. As the genus probably dates from the late Mesozoic we may have here local continuance of a formerly much wider, now much broken and discontinuous distribution. On the other hand, the present dispersal may be due to larval transportation, for the larvæ of the deep-sea Pelagodiscus (formerly called Discinisca) have been taken in the drag net very far from land and are known to live in the free and floating condition for nearly a month.

Crania.—This genus is very common throughout the Paleozoic and Mesozoic faunas of the northern hemisphere, and it is therefore probably safe to assume that it originated here. In any event Crania is today most abundant in northern oceans, where there are 4 species. In the southern hemisphere there are 3 forms, 1 off southeastern Australia, 1 in Antarctica, and 1 off western Patagonia. Its distribution seems to agree closely with that of Terebratulina.

Cryptopora has a greatly discontinuous distribution and may not owe its present occurrences to Gondwana. It was originally described (*C. gnomon*) from the north Atlantic, and is now known to be almost universal throughout the deep waters of this ocean from Davis Strait and Tromsö to off Morocco, the Azores, and the Canaries. The other form (*C. brazieri*) occurs in shallow water off New South Wales.

Terebratulina probably originated in the northern hemisphere and is known fossil since the Jurassic. Its greatest present specific development is about Japan, where 6 forms are known. In the northern hemisphere are living 11 species, against 3 in the southern hemisphere. In other words, the genus is common to almost all shores in the northern hemi-

sphere, and its other main distribution is along the north shore of Gondwana (2 species in the western Mediterranean), extending as far as the Antilles (1) on the west (none are present off western South America), on the east into the Indian Ocean (1), and probably across Asia in former Tethys to the Pacific. Along the southern side of Gondwana the genus probably spread along the shores of the Indian Ocean to southeastern Australia (1) and to the Cape of Good Hope (2). In the vast area of the Atlantic Ocean between Africa and South America there is but a single species, and this is the Antillean *T. cailleti,* occurring off Brazil at Pernambuco and Rio de Janeiro and as a relict in the mid-oceanic island Ascension.

Dyscolia wyvillii probably originated in ancient Tethys, where its ancestor, *D. guiscardiana,* is found in the Pliocene of Sicily. The living species is rare at the Maldives in the Indian Ocean, but is more common in the Atlantic off Spain, Portugal, northwestern Africa, and the Cape Verde Islands. As a relict it occurs off the Lesser Antilles. The other form, *D. crossii,* originally described from the east shore of Japan, is also reported by Fischer and Œhlert from Punta Arenas, in the Magellan Straits, and from New Year Sound. By combining the distribution of these two species we see that the genus has extended itself along the northern, western, and northeastern shores of Gondwana, and from the Austral waters to Japan, probably by way of Oceanica. While the genus is known only since the Pliocene, its large size and primitive loop makes it probable that its origin goes back to the Cretaceous. Its nearest relative is Terebratulina, which had its origin in the Jurassic.

Liothyrina.—This genus has the greatest number of species of all living genera (14), even more than Terebratulina. Its geographical distribution has recently been worked out by Blochmann (1908, plate 40) with the greatest care. The center of distribution was the north shore of Gondwana (Atlantic-Poseidon), where (western Mediterranean) at least 5 species are living. From the Antillean region (2) the genus extends down the west side of South America (3 species, 1 *L. uva*), and thence eastward into the Antarctic region to the Falklands, South Georgia, south of Africa, Kerguelens, Saint Paul (south Indian Ocean), and Kaiser Wilhelm Land to southeastern Australia. From the Australian region it probably spread northwest through Oceanica to Japan, where 2 species occur, but no linking forms are known to live now in the intermediate region. From the Mediterranean region the genus spread less abundantly northward along western Europe (2) into the Arctic region (1) of Jan Mayen, Iceland, and the east coast of Greenland. None are on either side of the North American continent. From the Magellan region

L. uva (widely distributed from Tehuantepec to Cape Horn and South Georgia) has crept north in the Atlantic as far as Buenos Aires, and with the breaking down of Gondwana, *L. cubensis,* an Antillean species here of wide distribution, has maintained itself with modification on Ascension as a relict, but is now recognizable, according to Blochmann, as a distinct geographic variant. Another associated relict here is *Terebratulina cailleti.* In regard to the remarkable distribution of the 3 closely allied forms of Liothyrina (*L. sphenoidea* in Lusitanian region, *L. cubensis* in Antillean, and the Ascension unnamed form), Blochmann (1906, page 701) states the following: "The 3 forms are the descendants of one that was bound to the shores of the central Mediterranean, which was extant up to Tertiary time, and since then the stock has been broken into the 3 discontinuous areas. Ascension we must regard as a part of the north shore of the land-bridge that once united Africa with South America."

Chlidonophora.—This deep-sea genus had its origin along the north shore of Gondwana, and *C. incerta* is found off Havana to the northwest of Trinidad and in the equatorial mid-Atlantic. The other form occurs in the Indian Ocean off the Maldives and Laccadives. The spread was through ancient Tethys.

Macandrevia.—Its most typical development (*M. cranium*) is now off the coast of Norway, spreading thence to North Cape and Greenland, east coast of North America at great depths, and south off Europe into the Mediterranean area. *M. tenera* occurs in Davis Strait, but there is no representation now in the Antillean region. In the Pacific, in the Gulf of Panama, 3 species occur, and 2 of these are also known in the deeps off Chile and Peru. Recently Blochmann has described a final species from the Antarctic Kaiser Wilhelm Land.

EQUATORIAL ATLANTIC

There is a great dearth of brachiopods in the equatorial Atlantic between 10 degrees north and 30 degrees south latitude. But a single shallow-water species is restricted to this great region. This is *Discina striata,* found in the littoral at Cape Palmas, Africa, and may be of Mediterranean origin. The few other brachiopods of this region are either northern relicts (2) of broken Gondwana, or deep-sea migrants (2), or shallow-water migrants from the Antillean regions (2). On Ascension, in mid-Atlantic, are found the relicts *Liothyrina cubensis* ? (now changed into another form according to Blochmann) and *Terebratulina cailleti* (also off northern Brazil). The only other northern migrant along the eastern shore of South America is the Antillean *Cis-*

tella barrettiana, dredged off Rio de Janeiro. Of deep-sea migrants into the tropical Atlantic are *Chlidonophora incerta* (on the equator in mid-ocean) and *Pelagodiscus atlanticus* (1 degree north, 24 degrees west). Mediterranean relicts, as *Liothyrina vitrea* and *Dyscolia wyvilii,* occur to the north of the region designated—that is, on the Cape Verde Islands.

From the Antarctic region have come the 3 migrants *Liothyrina uva* (north to Rio de Janeiro), *L. wyvillii* (Falklands), and the very characteristic boreal *Bouchardia rosea* at Rio de Janeiro.

In other words, along the shores of eastern South America (5) and off the western coast of Africa (1) are found but 6 species, there being 2 others in the deep sea and 4 relicts on oceanic islands, one of which occurs also off Brazil.

This survey of brachiopod distribution shows clearly not only the former existence of equatorial Gondwana across the Atlantic, but as well that its vanished Atlantic bridge still controls the distribution of living forms. We see that the genera of the northern Atlantic (Poseidon) distributed themselves in one direction, more or less widely throughout the northern hemisphere and in another pathway eastward into the Indian Ocean by way of the northern shore of Gondwana, but the main drift was far more decidedly westward along the same land by way of the Antillean region into the Pacific, and thence in the main down the west coast of South America into the Antarctic realm. Gondwana appears to have existed until middle Eocene times; the deciding land barrier between the fauna of the northern and southern hemispheres and the inter-hemisphere shallow-water genera followed either its shores or those of Oceanica and the northern Pacific bounding lands. What is true regarding the dispersion of brachiopods will probably be found essentially similar for other groups of animals with short non-feeding larval stages and inhabiting equatorial waters.

STRATIGRAPHIC SIGNIFICANCE OF OSTRACODA [1]

BY R. S. BASSLER

The recent bivalved crustaceans falling under the order Ostracoda are world-wide in their distribution both in fresh and salt waters. Not only are many of the species properly termed cosmopolitan, but they are also apparently unlimited bathymetrically. Today we find them swimming at the surface or creeping over the bottom in great colonies, and after the

[1] Manuscript received by the Secretary of the Society May 23, 1911.

death of the animal their shells are scattered far and wide, both on the land and in the water. Many of us in our field work have no doubt come across small pools, sometimes a foot or less in diameter, swarming with darting fresh-water ostracods or water fleas. In such instances, as evaporation proceeds, the pool will become a fairly solid mass of ostracods, and finally, when the water has disappeared entirely, their dead shells will be scattered by the winds as dust, sometimes to considerable distances. Fresh-water Ostracoda are therefore a factor in continental deposits. In the sea a similar wide dispersal, independent of the animal's life history, depends on the waves and currents, which bear the dead shells far from their habitat in life and scatter them broadcast, so that their final resting place may be in the deep-sea ooze or in the shallow littoral deposits.

Most of the modern as well as ancient Ostracoda are of microscopic size, and for this reason, even though in individual development they probably exceed almost every other class, they must always remain an inconspicuous element of any fauna. Another and more serious difficulty, especially in the study of the fossil forms, lies in the simplicity of shell structure found in some of the families. Among the recent faunules, species and even genera are established on anatomical characters, the shell being practically disregarded. It is a fact that several distinct genera have shells with essentially the same outline and surface characters. The difficulty, if not impossibility, of distinguishing such genera among fossil forms is obvious. For example, *Bythocypris cylindrica,* an abundant fossil in practically all of the Middle and Upper Ordovician formations, is closely differentiated from associated Cypridæ, yet the name possibly includes a number of distinct species. In outline and general structure its shell can be duplicated in several genera of living forms. On account of lack of character, this great group, which was more or less abundantly developed from the Ordovician on to the present, will not be mentioned in the further discussion.

From the foregoing remarks the bearing of the Ostracoda on paleogeography would seem to be insignificant had the class always possessed the characteristics shown by many of the recent forms. However, judging especially from their associates in the ancient continental seas, most of the Paleozoic representatives were much more limited in their habitat. Further, many of the Ordovician and Silurian species, particularly those comprised in the family Leperditiidæ, are not such inconspicuous fossils. While the average recent ostracod seldom exceeds a millimeter in length, certain Silurian *Leperditias*, the giants of the order, are 30 to 40 millimeters long. Again, there are hosts of forms like the Beyrichiidæ of

Paleozoic rocks and the Cytheridæ of Mesozoic and Recent times that are marked by great diversity of surface pattern, which lends itself to accuracy of specific discrimination.

Taking up the Paleozoic Ostracoda, we find that they have a distinct advantage over practically all other organisms in their occurrence in all kinds of rocks. While most abundant in limy sediments, they are also exceedingly common in highly siliceous strata in all kinds of shales, and even in relatively coarse, beach-worn sandstone. They are thus ubiquitous in their distribution and indiscriminate in the kind of water and sediments.

Many species supposed to be Ostracoda have been described from Cambrian rocks, but recent unpublished studies show that all of these are bivalved phyllopods. The first unquestionable Ostracoda, a few species of *Leperditia,* are found in the early Canadian rocks of west Tennessee, Missouri, Arkansas, and Oklahoma. Since they are wholly unknown in rocks of essentially the same age in the Appalachian region, it is inferred that the class, like many other groups of Paleozoic organisms, originated in or south of the Gulf of Mexico. It is only in the later stages of this period that the class attained representation in the more northern region. In the Ordovician a great expansion of the class occurred. The Leperditiidæ continue in full or increased strength, while the main families of Paleozoic time are introduced.

During the Middle Ordovician there seems to have been a shifting of the Ostracoda from the southern seas to the northern. This was accompanied by a considerable change in type. Thus, while the Ostracoda of the Stones River and the succeeding Black River faunas, which are of southern origin, consist almost entirely of Leperditiidæ, the next succeeding deposits from the Baltic region and the northern areas of North America contain very few or none of these, but instead a considerable development of the more primitive types of Beyrichiidæ. Further, all types of Ostracoda are rare, except a few like the cosmopolitan genus *Eurychilina,* in the rocks of Trenton age in the Mississippi and Appalachian valleys. The later Ordovician rocks contain a great influx of species quite similar to the late Black River forms as developed in the Baltic region of Europe and in America north of Missouri. During this time, then, the supply seems to have been derived by emigration from the northern seas rather than directly from the southern.

The earliest Silurian, Richmond formation, has the same generic representation; indeed, this continues with little change through the middle Silurian.

The later Silurian is marked by a very decided development of the genus *Beyrichia* and its related type, *Klœdenia.* A striking feature respecting these genera is that whereas the true species of *Beyrichia* are exceedingly rare in all American deposits of similar ages, on the other hand *Klœdenia* occurs on both sides of the Atlantic, while another genus, *Klœdenella,* obtained extraordinary development in the Silurian rocks of the Appalachian Valley and is almost unknown in Europe. True Leperditiidæ continue throughout the Silurian.

With the inauguration of the Devonian the general aspect of the Ostracoda changes markedly. True Leperditiidæ have practically disappeared, only a few stragglers occurring in the lower beds of the Helderbergian. The Beyrichiidæ have modified itno new generic groups with a quite different aspect. The hitherto poorly represented genera, like *Kirkbya, Octonaria, Thlipsura,* etcetera, now make up a considerable proportion of the total number. The general aspect of this ostracod fauna was not materially changed until the close of the Paleozoic. In abundance and variety American Devonian ostracods are in contrast with those of Europe because the latter are so poorly developed. It appears that the area of development and dispersal was again shifted back to South Atlantic waters. In fact, it seems that they were almost confined to these waters until well toward the close of the Paleozoic. In the Pennsylvanian a number of types not hitherto seen are introduced, the notched cypridinoids, primitive Cytheriidæ, and numerous cytherelloids. At this time a host of fresh-water forms are introduced—the first known. By this time the marine Ostracoda have become so cosmopolitan that the locus of their development can no longer be traced. Although still of aid in broad correlation, their value in detailed correlation and in the discrimination of paleogeographic provinces has been almost entirely lost. In succeeding time the fresh-water forms become more and more abundant. They are frequently found in the Red Beds of the West, and layers are often almost made up of them in the land deposits of the Cretaceous and Tertiary. While a few can be determined as land forms, many others are so similar to the marine Cypridæ that on their own evidence it would be almost impossible to decide that they are actually land forms and not marine.

From the foregoing it will be seen that while the Ostracoda are of very considerable value in stratigraphic correlation and throw light on paleogeographic problems up to the Pennsylvanian, their value in this respect seems to be much diminished in later times.

RELATION OF THE PALEOZOIC ARTHROPODS TO THE STRAND-LINE[1]

BY JOHN M. CLARKE

None of the Crustacea have shown a wider distribution than the trilobites. As to these trilobites there seems to be little in their mode of life to throw light on oscillations of the strand. They were not very sensitive organisms. Their primitive composition accounts for that in no small measure, so they adapted themselves to bathymetric differences of some considerable degree. We find their moults in the sands and the shales and the limestones of the Paleozoic, and doubtless some part of these have been washed out of their proper depth into the debris of the bottom, but their jointed skins are found as well in all these deposits, and we know they lived in shallow sands and deeper muds within perfectly easy reach of land waste. Their ready adaptability and their locomotive powers carried them easily over differences in sediment and depth, so in the habitude of these creatures there is really little to serve as a guide to geographic changes. In their anatomy there is more. I have long been impressed with the possibility that the relative development of the eye in these and other crustaceans, whether simple or compound, might afford some clue to the bathymetric conditions governing these animals. With our old knowledge it has seemed that the highly developed compound lenses in all the later trilobites, eurypterids, and in all the early shrimps and crabs must be a definite response to the amount of light received in their habitats; that the vaguely developed visual area in many of the Cambric trilobites, sensitive to light only in a general way along streaks on the head, should express a depth of water corresponding to a minimum of light received, but there were incongruities in these conceptions long before we knew the reasons for them. Æglina, with its enormous compound eyes, among its lensless associates of the Cambric, the undeniable evidence of shallow-water condition, in which the unspecialized eyes of the Cambric trilobites were produced, the counter-evidence of the highly developed ommatidia in the Phacopes and Dalmanites of the deeper waters of Siluric and Devonic, Walcott's demonstration that the visual areas in Olenellus bear lenses—these and similar incongruous conditions in the present deep sea from the Cystosoma, with its tremendous ocular development to the blind crab Willemœsia, go to show that the de-

[1] Manuscript received by the Secretary of the Society May 27, 1911.

velopment of the visual organ is partly a matter of growth and decline and in a large part an adaptation. The pigment about the ommatidia of a compound eye can by its readjustment adapt the organ either to the dusk or the brightness, and an elaborate compound eye thus fits all depths, shallow or great. I suggested last year that conditions of long isolation are sometimes, more often than we think, indicated by the resumption of primitive ornaments in the trilobite integument at a stage where in the normal progress of the race the creatures have burst into their climax of decoration, as in the trilobites of the austral Devonic, where even the sutural spines of the Cambric reappear in conjunction with the climacteric decoration of the race appropriate to the Devonic period. Here, too, isolation shows its effects in the development of expressions of lobal coalescence and pygidial decoration not elsewhere known. These characters in morphology are positive factors in the determination of the limitations of the strand, and morphology does in its total expression prove the most dependable index of geographic differences. The eurypterids, in their life history and in their climax, are far more sensitive to geographic changes. The few early eurypterids we know were doubtless marine, and the creatures gradually acquired the brackish-water habit of their climax, which seems to have eventually changed to a fresh-water life. The value of these creatures as indexes of geography at any one time in the earth's history is therefore quite evident.

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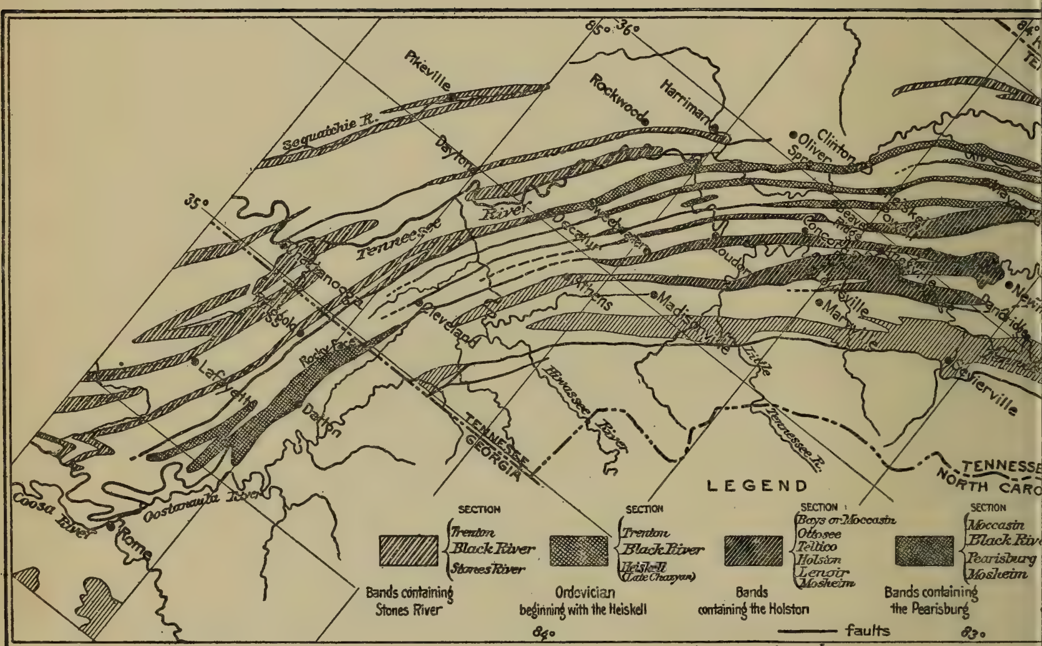

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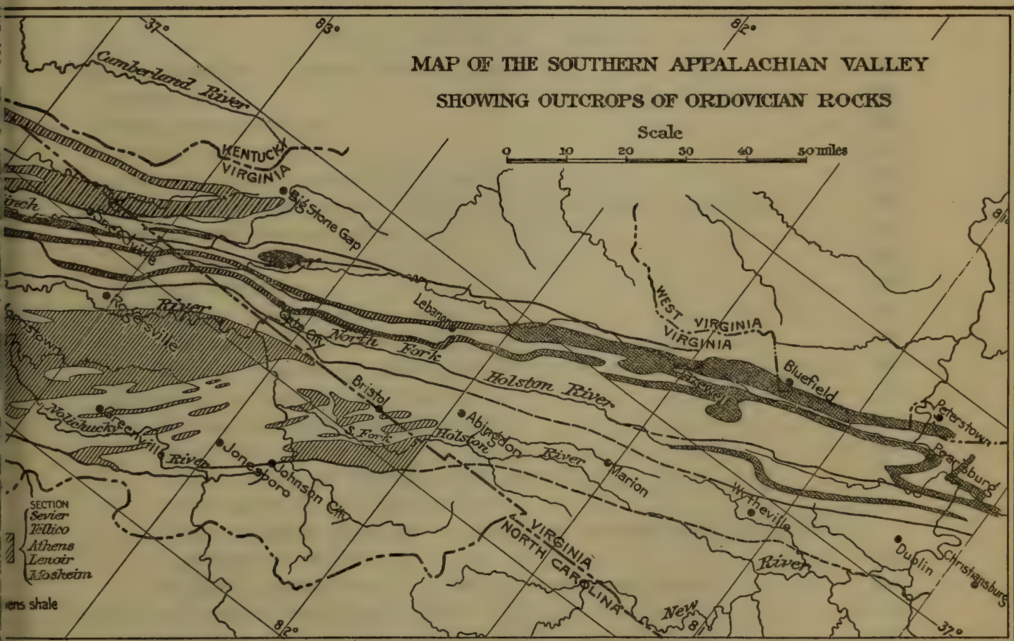

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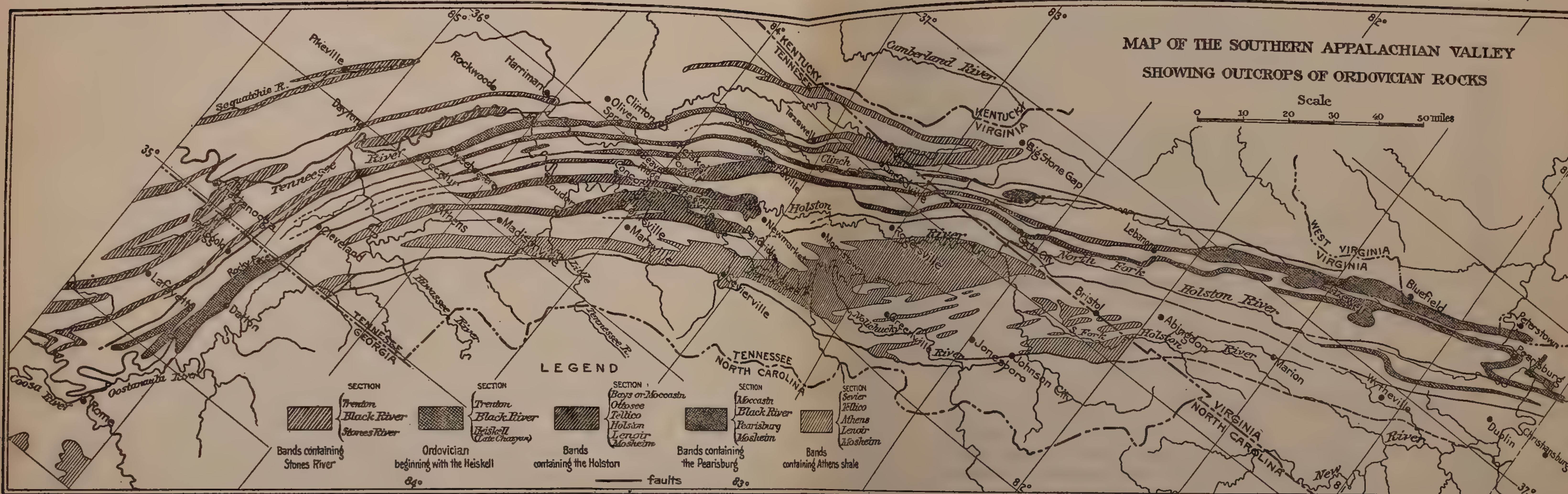

MAP OF SOUTHERN APPALACHIAN VALLEY

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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REVISION OF THE PALEOZOIC SYSTEMS[1]

BY E. O. ULRICH

(Presented in abstract before the Society December 30, 1908, and December 28, 1910)

CONTENTS

[1] Published by permission of the Director of the U. S. Geological Survey, who, in view of the fact that this paper presents a new classification, at variance with adopted usage, disclaims responsibility for the classification, correlations, names, and redefinitions.

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PART I. INTRODUCTORY CHAPTERS

Present Instability in stratigraphic Classification

CAUSES

The obvious unrest of the present day in matters pertaining to geologic chronology should be ascribed, I think, chiefly to the fact that stratigraphic knowledge has progressed far beyond the stage of prevailing schemes of classification. These schemes do not fit the known conditions. Not only were they founded on a mere fraction of the mass of data now available, but also the criteria used were frequently misinterpreted. Besides, the pioneers in this branch of geology had no conception of the complicated and variable conditions for which we now have to account; hence their practice has resulted in an inconsistent and incongruous arrangement of stratigraphic units.

But the weakest feature in these classifications is that their original framers availed themselves almost exclusively of a single kind of evidence, namely, that afforded by the fossil faunas and floras. If the fossils of geographically separated formations agreed in general aspect and composition, and especially if the percentage of the identified or supposed vicarious species was large, then the stratigraphic units were correlated. The possibility of locally surviving species or faunas, or of local variations in development, was not considered.

But these early practices were merely the extreme swing of the pendulum. The great success attending the use of fossils in correlation when compared with the results accomplished under the wholly incompetent methods previously employed not only placed stratigraphic geology on a firm basis, but induced a blind and unquestioning confidence in paleontologic evidence. The word "blind" is used advisedly, because an unprejudiced analysis of correlations by fossils in the fifty years preceding the past decade shows beyond denial they were made in practical disregard of factors vitally concerned in the production of local facies of faunas.

Under the circumstances it is not surprising that the efficiency of fossil evidence began to be questioned; that good philosophers began to discuss "shifting of faunas," to use expressions like this, "it required a long time for the *Olenellus* fauna to encircle the globe"; or for another to say "the very fact that geographically separated faunas are the same proves they are not contemporaneous." Presently others, chafing under the yoke of the "Paleontological autocrat," were suggesting classes of evidence and modes of correlation that might entirely supersede that based on fossils. Dual nomenclatures are proposed, new principles of correlation are suggested, and a symposium of correlation is arranged. It is

the unrest preceding a revolution. What shall we do to direct it toward the promotion of our science?

DUAL NOMENCLATURES

As a result of my investigations I am opposed to a dual nomenclature, or, indeed, to any scheme tending to divorce paleontology from stratigraphy. The study of fossils apart from their stratigraphic relations is pure biology. With geologists the study of fossils should be a means to a definite end, and that end the elucidation of the geologic history of our earth. Geologic time should be measured by stratigraphic units, not by the indefinite duration of successive but overlapping dominant types of life. The time scale was not built up of life units, but of stratigraphic units. Indeed, the only competent means of estimating geologic time is based on ratios of deposition and on other considerations that are equally distinct from biologic investigations. The geologic time scale, therefore, is an essential feature of geology and not of biology.

The lithologic scale, like any faunal scale, is necessarily a local affair. In other words, both scales are founded on factors that are more or less strictly local in their typical development and subject to great variation when pursued beyond these areas. Neither, therefore, is capable of supplying data for a positive standard. So far as I know, there is but one possible standard by which geologic events and sedimentary rocks may be classified, and that is by *time* units—in other words, the chronologic standard.

MUTUAL CONCESSION

It is evident that the remedy for the present difficulties lies not in divorce, but in mutual concession and adaptation to prevailing conditions. Faunal, diastrophic, and lithologic criteria are complementary, and each kind may and should be used to check the other two. None of the three classes of evidence is competent by itself to insure a refined and true classification of geologic time, but between them we may hope to construct one. Let us reconstruct, or rather amend, our stratigraphic columns so that they shall indicate all well defined lithologic boundaries as well as the important faunal changes and the broader crustal movements that as a rule caused both.

Further, let us draw the various boundaries as nearly as possible in accord with the composite evidence of all classes of criteria. I should not object to considering even such non-geological matters as exigencies of mapping. Often a lithologic boundary could be drawn just as well or better at a line indicated by diastrophism or by a sharp faunal change as at the plane selected by the geologist without regard to either of these criteria. There is need for closer cooperation, and, more important still,

for a spirit of concession and compromise in matters of detail and method between the lithological stratigrapher and the stratigraphical paleontologist. Neither should be asked to sacrifice important principles.

POSSIBILITIES OF CORRELATION BY FOSSILS

There are limits beyond which correlation can not go. Within a single stratigraphic province, as, for instance, the Mohawkian area, extending from Cincinnati southwestward to northwestern Alabama and southeastward to the southwestern corner of Virginia, or, in the Silurian province, embracing southern Indiana on the north and west middle Tennessee on the south, satisfactory correlation is possible to the smallest units that it is practical to map. And in such cases no other evidence than that afforded by the fossils is essential. But when it comes to correlating minor stratigraphic units of distinct basins, then the fossils need the help of other criteria. The fossils supply the first step in the process. They give us a reliable clue as to the boundaries of the major divisions. Finally, the principles of diastrophism fix these with greater precision and supply data on which correlations of minor rank may be based. But with no fossils at all it would be simply impossible to attain satisfactory results. Had not a Walcott found remains of *Olenellus* in the quartzitic sandstones on the east side of the Appalachian Valley, many areas now known to be lower Cambrian would still be classed as Medina; and had not a Ruedemann discovered certain Eurypterids in the Shawangunk sandstone, we might never have been able to prove that this formation also is not of Medina age. We might cite local successions of sandstone, shale, and limestone differing in no physical respect from similar cycles of sedimentation elsewhere that could never have been distinguished except for the infallible clue given by a few or, may be, but a single fossil.

On the other hand, the evidence of the fossils—often used by the paleontologist with such confidence and finality against the conclusions of the structural geologist that the rather disrespectful appellation of "autocrat" may sometimes appear justified—is not an obvious quality of the fossils themselves. The sequence of faunas as known today is the result of long continued and laborious research in areas of undisturbed stratigraphic succession. Faunal zone after faunal zone was located and their respective relations to certain lithologic units noted. Thus piece by piece the column has been built up. But the very foundation of the training of the modern paleontologist, who is not merely a biologist, makes him a good stratigrapher. Besides, there is no phase of diastrophism or of biology that he does not use or is not willing to use in the improvement of his determinations. His training is broader and he must work harder than any other class of geologist. Yet the paleontologist

has often been disconcerted when the unquestionable succession of beds showed he had gotten things upside down or on the wrong plane. And he knows better than any one else that his information on the mutation and succession of faunas and floras is far from complete. Still it is a fact that fossils in experienced hands afford by far the most competent and reliable evidence now available in stratigraphic correlation. Likewise in the elucidation of the physical as well as the organic history of the earth fossils play a most important part. Finally, it is true that without their aid stratigraphy could never have become a science. The biologic part of paleontology may be considered separately from geologic processes, but stratigraphy can not exist apart from paleontology.

Investigations tending toward Revision of stratigraphic Classification

THE NATURAL BASIS OF GEOLOGIC TIME DIVISIONS

Nearly twenty years ago I began to entertain doubts as to the prevailing classification of Paleozoic rocks. That crustal movements considered in connection with faunal evidence afforded the best means of revising the classification on a sound and consistent basis did not appeal to me till a few years later, when I was engaged on the correlation of the Ordovician beds of Minnesota.[2] The idea was too new and vague to be employed then. It had first to be tried out in the field. Since my connection with the Federal Survey in 1897, I have enjoyed abundant opportunities to apply and test its principles. In my opinion, the results are eminently satisfactory.

The theories advanced in "Seas and barriers in eastern North America" by Ulrich and Schuchert, in 1902, have been sustained in every essential feature by subsequent investigations.[3] Chief among these is the permanence of certain continental lines of elevation separating areas of depression. Along the former, discontinuities in sedimentation and subsequent overlaps recur frequently, while in the intermediate spaces deposition was much more continuous. Obviously the areas of frequent elevation and consequent emergence afforded the best, and sometimes the only, evidence of crustal movements. Assuming the general truth of

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[2] Geological and Natural History Survey of Minnesota, Final Repts., vol. iii, introduction, 1896.

[3] The only important modification of the views expressed in the work cited is that the deposits on opposite sides of the Appalachian barriers are as a rule not contemporaneous but successive. In other words, that the concerned continental seas were smaller and shifted from time to time, oscillation causing repeated sea withdrawal from troughs to the east of the barriers before other waters filled the basins to the west of them. This modification removes the principal objection to the original theory, in that it eliminates the difficult conception of long and very narrow land barriers.

this proposition, the chief aim of my stratigraphic and paleontologic investigations in the past decade has been the location of such lines of predominating upward movement. The determination of these lines is

FIGURE 1.—*Sketch Map of southeastern North America*

Showing Appalachian troughs and principal lines along which stratigraphic overlaps are common

deemed one of the best results of a long series of personal field studies and comparisons of faunas gathered with a view to illustrate minute details of stratigraphy as well as their geographic distribution and variation. Moreover, the plotting of these lines has been an essential factor

in the construction of paleogeographic maps. At the same time their study affords apparently the only reliable grounds on which a natural yet practical classification of time and stratigraphic units may be based.

CHAMBERLIN AND SALISBURY'S CLASSIFICATION

As my views concerning a natural basis of geologic time division are essentially those of Chamberlin and Salisbury,[4] it follows that I regard their classification of the American stratigraphic column as a change in the right direction and the best yet published. The chief merit of their classification lies in the endeavor to make the systems approximately coordinate in time value. In the Paleozoic part their scheme is somewhat inconsistent in the matter of drawing the systemic boundaries and faulty because of miscorrelations and lack of information. For example, in the case of the Devonian, also the Pennsylvanian, they draw the lower boundary at the beginning of a submergence following a period of broad emergence. The base of the Mississippian, on the contrary, is drawn above the Chattanooga shale; hence considerably later than the beginning of the great submergence that followed the final Chemung emergence of the Devonian. Regarding the respective bases of the Silurian and Ordovician, incorrect correlations of formations are responsible for inconsistencies in their delineation. In the sections of New York and the Appalachian Valley the base of the Silurian is drawn at the beginning of the epoch of greatest retreat of the Ordovician sea. In the Ohio and Mississippi valleys and in the far west it is drawn at some horizon succeeding the deposits of the first great advance of the Silurian seas. The base of the Ordovician varies for other reasons, but chiefly because it was thought to occur at some undeterminable horizon within a vast thickness of limestone.

It is only in the past 10 or 12 years that, as I believe, the true relations of the Cambrian to the Ordovician have begun to be understood. Most of the information gathered on the subject during this time is as yet unpublished, but the gist of it will be presented on this occasion. The study of the Neopaleozoic rocks has shown that their diastrophic history also has not been adequately considered, and that the classification of their stratigraphic units is greatly in need of revision. Unfortunately, the facts on which the proposed innovations concerning these later deposits are based can not be discussed as fully now as it is hoped they may be in the future. The facts are in hand, but space is lacking.[5]

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[4] Geology, vol. iii, 1906, pp. 191-196.

[5] Since reading these "introductory chapters" at the Baltimore meeting of the Society, Prof. Charles Schuchert's great work on Paleogeography of North America, presented at the same session, has been published. Although based on the same general considera-

SHIFTING OF FAUNAS

General discussion.—The idea of "shifting of faunas"—that is, tangential transgression of faunas in migration—is of course true theoretically and in fact. The passage between two points requires some, however infinitesimal, lapse of time. But, speaking geologically, the proposition is, in my opinion, purely theoretical. Its practical application in the correlation of geological formations seems impossible and can be assumed only in entire disregard of the general coarseness of geological time units. Admitting, for the sake of argument, Walcott's very conservative estimate of Paleozoic time as representing something like 17,500,000 years, and that this great sum is divisible into less than 100 succesisve time units of sufficient importance to be inserted in a general time scale, we find by simple division that the average length of time represented by each formation is not less than 175,000 years. Walcott's estimate being based on an aggregate thickness of 21,000 feet of Paleozoic sediment in the Cordilleran sea, the average time value of each foot of deposit is accordingly about 833 years. For limestone deposits, of course this value is much greater. Now, while a few beds or formations 50 feet or less in thickness may be recognized by correlation over wide areas, the average interval within which satisfactory correlation is possible is not less than 100 feet. Multiplying this by 833, the average time value of practical correlation units would be about 833,000 years. Considering that the living shell *Littorina littorea* required less than 50 years to migrate along the Atlantic coast from Halifax to Cape May, a distance of over 700 miles,[6] it might at the same rate encircle the globe no less than 46 times in the time-equivalent of a single Paleozoic correlation unit.

If Paleozoic invertebrates traveled only one-fiftieth or one-hundredth as fast as this living shell, then we may reasonably assert essential contemporaneity for stratigraphic correlations extending across the continent.

As evidence opposed to the slow progress of faunal migrations, I would cite the great geographic distribution of the Richmond faunules, which will be discussed in the argument for low relief of Paleozoic lands. One of these Richmond faunules has been recognized at numerous localities in the broad area limited on the east by Illinois, on the west by Nevada, on

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tions, and to a large extent on the same or similar facts, the classification adopted by Schuchert, while agreeing in essential respects, differs in several important details from my own. It was chiefly to give me an opportunity to discuss these differences that the publication of the present work was delayed a year.

[6] Case of *Littorina littorea;* first observed at Halifax, Nova Scotia, 1852; at Bathurst, Bay of Chaleur, 1855; coast of Maine, 1868; Portland, Maine, 1870; Salem, Massachusetts, 1872; Barnstake, Cape Cod, Massachusetts, 1875; Woods Hole, rare, 1875; common, 1876; New Haven, Connecticut, 1880. (E. S. Morse: The gradual dispersion of certain mollusks in New England. Bull. Essex Institute, vol. xii, 1880, pp. 3-8.)

the south by El Paso, Texas, and on the north by the Arctic regions. Everywhere it seems confined to a bed less than 50 feet thick.

Another striking instance is the Lowville (Birdseye) limestone, which has been recognized by identity of fauna and extraordinary persistence of lithologic characters from Canada to Alabama, and westward to north Arkansas and east Missouri. Every feature connected with the formation as developed in middle Tennessee and central Kentucky—dominant fossils, succession of faunules, lithology, a sharp but not conspicuous break beneath separating it from upper Stones River limestone and another more conspicuous but less important hiatus above—can be duplicated in the typical outcrops of the formation in New York. If this parallelism does not establish essential contemporaneity, then we may as well cease trying to correlate.

A third instance, differing decidedly from the preceding in that it involves transgression westward across barriers, is afforded by the Martinsburg and Utica shales. The Martinsburg shale occupies the interval between the Massanutten sandstone above and a limestone beneath. On faunal and diastrophic evidence the last bed of this underlying limestone is proved to be late Black River or earliest Trenton in age. The lower part of the northern Appalachian equivalent of this shale has been generally referred to in New York and elsewhere as Utica, but it is in fact much older. The true Utica is found well up in the eastern shale series. Eastward from Little Falls, New York, more and more of Trenton time is represented by shale, but to the west of that town we find limestone instead of shale. The typical Utica finally rests on a full development of Trenton limestone, and thus is proved to represent a later stage in the westward transgression of the almost continuous eastern shale sedimentation.

The case of Triarthrus becki.—The trilobite *Triarthrus becki* has nearly always been regarded as the most characteristic fossil of the Utica. It is, as indeed is the whole genus, a migrant from the Atlantic; and it seems to have been an excellent traveler, since we find it generally with the advance guard. The first known occurrence of this species in America is in the basal 10 feet of the Martinsburg. When the eastern sea again transgressed westward during the true Utica this ambitious rover came in on the first wave. That *Triarthrus becki* maintained this characteristic is shown by its abundance at Cincinnati, Ohio, in the 1 to 26 feet of Fulton shale which represents the extreme southwestern limit of the true Utica invasion.

This trilobite reappears in the Cincinnati section in the Southgate member of the Eden shale approximately 150 feet above its occurrence in

the Fulton, or true Utica. The limy shales of the Economy member of the Eden between the two occurrences contain a prolific fauna differing radically from the preceding Utica life. A few species of the earlier fauna, notably two of its graptolites (*Climacograptus typicalis* and *Mastigograptus tenuiramosus*) continue into the succeeding Eden faunas; but the general aspect of the latter, with their wealth of bryozoa, calcareous brachiopods, crinoidea, pelecypods, and gastropods, all indicative of warm water, shows that very different marine conditions had abruptly set in. The character of these changes might be discussed with advantage, but as they are not immediately essential, we will pass to the point it is wished to make, namely, had the true Utica failed to reach Cincinnati, or if the bed did not come to the surface at that point, in which case *Triarthrus becki* would have been known here only from its later Southgate Eden occurrence, either of two inferences might have been drawn. According to the first, the Southgate Eden would be correlated with the New York typical Utica and the marked differences in their faunas ascribed to local variation. If, on the other hand, the newer age of the Southgate had been recognized, then it might well be cited as an instance of shifting faunas. That neither of these possible inferences is correct is indicated by the earlier occurrence at Cincinnati, not only of the trilobite, but also a number of its constant associates in the New York Utica. This interpretation is finally established by a similar reappearance of *T. becki* in New York, where Walcott and others before me found this species in the lower part of the Lorraine shales, in beds apparently exactly correlatable with the Southgate shale at Cincinnati.

As interpreted by me, the known facts concerning the distribution of the *T. becki* fauna in the Utica and Southgate members of the Eden indicate, not a slow, tangential shifting of the fauna, but a brief revival of conditions—presumably subsidence in the region of the Saint Lawrence or of the Chesapeake Bay region—that permitted a second rapid invasion of the interior basins as far west as Cincinnati.

Rate of progress in migration of faunas.—In my opinion, most instances of supposed "shifting" rest on incomplete observations of reappearing faunal elements. These successive occurrences were not accomplished by slow geologically measurable stages, but they took place at rates of progress so rapid that it is impractical, if not impossible, to express them by the smallest formational unit now recognized.

That marine faunas usually migrated as rapidly as the invading waters themselves is shown also by the fact that where a widely transgressing sea is represented locally by perhaps only a few inches of deposits these may be, and usually are, filled with characteristic fossils. For instance,

the Fusispira bed of the Prosser limestone, a southern Minnesota and northern Iowa formation, is locally represented in the Mohawk Valley of New York by a few inches to a few feet of beds at the base of the Trenton limestone. Wherever this thin representative has been observed it is crowded with characteristic Fusispira bed fossils. Partial studies of collections in the National Museum from three localities in the Mohawk Valley have so far brought out over 30 of such species. Similarly, the widely distributed western Fernvale Richmond, whether 1 foot or 25 feet thick, was as a rule immediately charged with its diagnostic fossils. This could not be so if the migration of the faunas had required stratigraphically measurable time.

The rapidity of faunal invasions and migrations is shown perhaps even more convincingly by the early appearance of a new fauna in areas far removed from the point of ingress. The evidence is especially strong when the formation containing the fauna is represented in such distant areas by its fullest known development. For example, in the Stones River at Martinsburg, West Virginia, where this group of limestones attains its maximum known thickness of over 1,200 feet, the fossiliferous layers began either directly above or within a few feet of the unconformity at the top of the underlying Beekmantown. And yet this Stones River fauna invaded the continental basins from the Gulf of Mexico. If the migration of the fauna had been slow, as compared to the rate of sedimentation, its appearance at Martinsburg must have been delayed to a time marked by some correspondingly younger bed.

Many more, and in part varying instances, but all tending to prove that migrations of faunas, unimpeded by physical barriers, progressed too rapidly to be measured in distinguishable geologic time units, might be cited. Lacking space, I must refrain, and trust that the few offered will prove sufficient for present purposes.

RECURRENCE OF SPECIES AND FAUNAS

General discussion of recurrence.—The Paleozoic rocks of America afford many instances of species that entered periodically into the faunal history of the interior basins. These species are in perhaps every case also well represented in the rocks of other countries than our own. They were of vigorous stocks and generally very prolific. On account of their vigor they existed, with a minimum of modification, through a longer period of time than more sensitive species. When conditions were favorable they migrated from their permanent range into the available basins of the interior. In these they spread with great rapidity, as is indicated by their sudden appearance and extreme numerical develop-

ment. In citing examples of such periodic emigrants the most striking doubtless occur among the Brachiopoda. Varieties of *Dalmanella testudinaria,* for instance, appeared in the Mohawkian and Cincinnatian rocks of Kentucky and Tennessee no less than five times; *Plectambonites sericeus* is represented by barely distinguishable varieties in the Stones River, the late Black River, in late Trenton, in the Eden, and finally by two mutations in the Richmond; *Atrypa reticularis* first appears in the Clinton, and then continued, with occasional intermissions, to hold its own to near the close of the Devonian; *Leptæna rhomboidalis,* the Methusalah of fossils, enjoyed two rather brief trips to the interior in Ordovician ages, lived there rather generally during the whole of the Silurian, and reappeared again and again during Devonian and early Mississippian times.

If the several invasions of such broadly conceived species can be discriminated—as a rule it is not difficult to do so—they constitute excellent datum planes in correlation. If, however, the paleontologist will not take the trouble to learn the often very slight modifications of the specific type that distinguishes each appearance from the other, then they are more likely to prove stumbling blocks than aids in determining equivalence.

Moreover, as such long-ranged species are generally very abundant, when they occur at all, they will, of course, always figure in lists of standard dominant species, prepared according to the suggestions of Prof. H. S. Williams. The listing of names of species like *Leptæna rhomboidalis, Atrypa reticularis, Plectambonites sericeus,* and *Dalmanella testudinaria,* without designating exactly the particular mutation of each intended, can not possibly tend to accuracy in correlation. Indeed, they may lead to positive error, since the less common though more characteristic species of a formation may be crowded out of the list by their ubiquitous but not diagnostic competitors.

Recurrence of the Catheys fauna.—Three excellent and instructive examples of recurrent faunas deserve mention here. The first of these cases is displayed in the Ordovician rocks of central Kentucky and middle Tennessee. The Catheys formation in Tennessee is the uppermost of three formations which together are regarded as representing the Trenton limestone of New York. The fauna of the Catheys really embraces two faunules, both of which reappear in more or less modified forms in subsequent deposits. The first consists chiefly of conical and massive corals belonging to the genera *Streptelasma, Stromatocerium* or *Labechia, Tetradium,* and *Columnaria.* These conspicuous fossils are confined to the lower half of the Catheys, but reappear in a well marked zone well up in

the Leipers formation. In Tennessee the latter formation rests on the slightly eroded top of the Catheys, so that the local stratigraphy does not afford an adequate conception of the extent of the interval beween the first and second appearance of these corals. Ohio supplies the missing links, these being the 550 feet of Eden shale; the lower 300 feet of which is black, represents the Utica, and is known chiefly from deep wells; the upper 250 feet being the shale which constitutes the bulk of the Eden at Cincinnati. These same corals, or rather their scarcely distinguishable descendants, appear once more in the Richmond series of Ohio, Indiana, and Kentucky. This last appearance is more remarkable than the second for the reason that in this case the Cathey corals (including *Columnaria alveolata*) are accompanied by *Columnaria halli*, which is known elsewhere only in upper Stones River, Lowville, and Black River rocks; by *Protarea vetusta*, a Lower Trenton species, and by several types of brachiopods and ostracods commonly found in the Trenton, but unknown in the often extremely fossiliferous intervening formations.

The second faunule of the Catheys consists largely of bryozoa, with smaller numbers of brachiopods, pelecypods, and gastropods, the general aspect of the fauna being extremely like that of the Maysville formations of Ohio and Kentucky and the Leipers formation in Tennessee. When I first met this facies of the Catheys in central Kentucky I did not hesitate to correlate it with the Maysville at Cincinnati. It seemed to me that I recognized an old acquaintance in each fossil, but when the collections had been carefully studied I knew better; they were near—often very near—relations, but never exactly the same. At the same time it was learned that these progenitors of the Maysville fauna were always accompanied by at least a few species that were easily distinguishable from all of the Maysville fossils. These species, therefore, are preeminently the characteristic fossils of the Catheys formation, despite the fact that the most of them could not appear in a list of "standard dominant species" drawn up according to the plan of Professor Williams. His list of dominant Catheys fossils would be essentially if not exactly the same as for the Maysville.

Utican aspect of the Maquoketa fauna.—Another interesting, and at first sight perplexing, reappearance occurs in the Maquoketa shale of the Mississippi Valley and in the essentially contemporaneous Sylvan shale of the Arbuckle uplift in Oklahoma. Aside from the molluscan fauna that is limited to the basal layers and a bryozoan and brachiopod fauna found in magnesian shale at the top of the Maquoketa, the fauna of these two otherwise black shale formations consists almost entirely of graptolites, phosphatic brachiopods, and pteropods. The species are nearly all

so closely allied to well known Utica shale fossils that unless they are very thoroughly compared the distinctions may easily be overlooked. Since the lithologic character of the three formations likewise is practically identical, it is not surprising that they have been regarded as contemporaneous. However, the facts in the case are that the Sylvan and Maquoketa shales overlie unquestionable Richmond faunas, while the Utica lies just above the Trenton at the base of the Cincinnati series.

Recurrences of the Spergen fauna.—We will now briefly consider the most remarkable case of recurrent faunas so far discovered in America. This fauna was first described by Hall in 1858. Since that date it has been known as the Spergen, the name being taken from Spergen Hill, Indiana, where Hall's original material was collected. Essentially it is an association of diminutive molluscs—mainly gastropods and pelecypods of many species—found almost invariably in oolitic limestone.

The first appearance of this diminutive fauna that we can definitely locate in the geological column is in the Warsaw formation. Here, however, the fauna is represented by comparatively rare individuals of only a few of the characteristic species. This may be due to the fact that conditions favoring the deposition of oolitic limestone did not then prevail in the areas in which the Warsaw is found.

The second appearance in the Mississippi Valley is in the Spergen limestone, in the Indiana outcrops of which the fauna was first discovered. In the oolitic limestones of this formation it occurs locally in extraordinary development, not only in the way of individuals, but also in species.

Following the Spergen oolites, the section passes through 300 feet or more of Saint Louis limestone, distinguished lithologically from the beds next beneath and above it by its more compact texture, darker color, and more cherty character. Though the Saint Louis limestone is rather generally fossiliferous, the distinctive Spergen fauna is wholly unknown in it.

The formation next above the Saint Louis is the Saint Genevieve limestone, the beds making up the lower and middle parts of which are prevailingly oolitic. Now, many of these Saint Genevieve oolites are simply crowded with typical Spergen shells. Hand specimens might be selected that could not be distinguished from samples of typical Spergen rock. Out of 43 species found in the oolitic beds of the Saint Genevieve, no less than 35 have been recognized as belonging to the Spergen fauna. Fortunately one or more of a half dozen corals and crinoids that experience has proved to be strictly characteristic of the Saint Genevieve have never failed to reward a few minutes of search.

The fourth appearance of the Spergen fauna occurs again in oolitic

limestone belonging to the Tribune formation of the Chester group. This is the third formation of the Chester group, the Saint Genevieve being the first and the intervening Cypress sandstone, 100 feet or more in thickness, being the second. In something like 20 pounds of Tribune oolite, representatives of no less than 40 of the 70 species originally described by Hall from the Spergen limestone of Indiana were found. Many of these Tribune examples perhaps might be distinguished from their Spergen progenitors, but I doubt if any paleontologist would think of applying even subordinate designations to them if he did not know that they occur in a much younger formation than the Spergen limestone. Since this fauna in the Tribune is always associated with other fossils whose age is in no case open to misinterpretation, I question again if it is worth while, from the stratigrapher's standpoint, to undertake the task of discriminating between the Tribune and Spergen representatives of the fauna.

Finally, I have observed in southwestern Missouri a fifth, and possibly a sixth, occurrence of the Spergen fauna in limestone lenses of a shale thought to be late lower Pottsville in age. One of these may correspond in age to the occurrence in Montana of a mixed Spergen and Pennsylvanian fauna reported many years ago by Meek.

Value of fossil evidence in correlation not seriously impaired by recurrence of faunas.—It may appear to some that these cases of recurring faunas—or, as Williams probably would call them, shifting faunas—must greatly impair the generally accepted view as to the time value of fossils. As I understand the cases, they do not seriously affect the value of fossil evidence as a whole. Neither does it seem to me that the correlation of geographically separated deposits, by which I mean the determination of their contemporaneity, is hopelessly complicated even in the case of faunas known to have two or more distinct time values. Intelligently administered, the evidence of the fossils of a formation containing a fauna characterizing two or more formations that are separated by intervals in which it does not occur is scarcely less diagnostic than in the case of faunas appearing but a single time in the visible geologic scale. In my opinion a fauna reappearing after a long absence must indubitably have undergone some probably recognizable mutation in at least the combination of forms, if not also in the specific characters of the original elements.

The circumstances that have permitted invasions of the interior seas by extracontinental faunas, and also those that brought about intercommunication between the more or less distinct inner basins, can in most cases, I believe, be determined with a reasonable degree of probability

and accuracy. The discussion of these conditions, which are highly important and bear directly upon problems of correlation, will be found in Part II of this work. For present purposes it will suffice to say that differential crustal movements and the consequent birth or rearrangement of land and water areas are the prime causes of the apparent discordances between contemporaneous faunas of neighboring and more widely separated areas. In many cases also the abrupt local extinction of faunas and their replacement by others of widely different origin is attributable to the same cause.

Uniform composition of widely transgressing faunas.—Reference has already been made to several instances illustrating the essential constancy of widely distributed faunas. Such constancy is usually confined to deposits within areas bounded by comparatively permanent lines of elevation. In some instances, however, erosion and concomitant sea filling produced a condition so closely approximating uniformity of surface relief that submergence immediately succeeding spread far and wide over the usual barriers. The Richmond fauna is one of the greatest and perhaps the most convincing of these widely dispersed faunas. While this Richmond transgression affected areas chiefly to the west and north of Mississippi River, the Onondaga Devonian fauna may be cited as similarly transgressing the area to the east of that river. The Onondaga is a fine example of a thin limestone formation overlapping a nearly base-leveled area. It failed to top either the Cincinnati or the Nashville dome, and it seems to be absent, at least as a limestone, over a large part of the Appalachian Valley; but, nevertheless, it is to be regarded as the first great inland advance of the Devonian sea.

The late Devonian, or, as I prefer to call it, the early Waverlyan, black shale transgression represented, according to my interpretation, by the lower Woodford of Oklahoma, the Chattanooga shale of Arkansas, Missouri, and Tennessee, and the upper beds of the Ohio shale in Kentucky, Indiana, and Ohio, is another good example. A fourth, hitherto not properly appreciated, transgression, following a period of evident base-leveling, occurred toward the close of the lower Pottsville. Elevation and subsequent erosion of the southeastern part of the continent, probably accompanied by continental creep and accentuation of old submarginal downwarps, resulted in enormous, somewhat local deposits of clastic material in West Virginia and Alabama and in the area south of Arkansas River in Arkansas and Oklahoma. Later crustal movements introduced a more general subsidence permitting the Pottsville sea to spread rapidly northward to Ohio on the east and to Kansas and Illinois in the

Mississippi Valley. At the same time it advanced westward, covering areas previously land in Oklahoma and central Texas.

Extent of Paleozoic Continental Seas

General Discussion of the Subject

The relief of Paleozoic land areas—a subject to be discussed in detail under the head of Displacements of the Strandline—was generally very low. At certain times, however, notably the early Cambrian, early Silurian, and early Pennsylvanian, the highly clastic character of the sediments justifies the belief that the submarginal lands—that is, the areas outside of the great interior flat of the continent—were high enough to encourage abundant and rapid erosion. Comparatively high lands, though more limited in extent, are indicated also in the early and late parts of the other periods (see pages 467 to 477), but following their reduction each of the periods entered a long enduring stage of low lands and shallow epicontinental seas. The evidence of still other crustal movements during the course of each period is preserved in the stratigraphic and organic records. These last movements (see pages 405 to 430), though less violent than those marking the beginning and close of the periods, nevertheless effected often greater geographic changes. Under nearly baseleveled conditions it is readily seen that a slight tilt of the continental platform, or only a small subsidence of the same, might have produced great extensions of the seas, and when the movement was reversed, equally great withdrawals. Admitting an average low relief, it follows that erosion during a long part of each period must have been very slight. Following this, it is plain why even very long intervals of emergence may be so obscurely recorded in the stratigraphic succession that the fact of emergence may be very difficult to establish by physical evidence alone.

Numerous instances of discontinuity of sedimentation, and presumably emergence, have been observed, the time values of which, if suspected at all, could not possibly be determined without the evidence of fossils. Assuming the competency of their evidence, the facts concerning a few of the more convincing, in part unpublished, instances will be cited in the hope that they may be accepted as establishing the following propositions: (1) prevalency of conditions approximating baseleveling over large areas of the Paleozoic continent; (2) the present distribution of Paleozoic epicontinental formations is fairly indicative of the extent of their respective seas; (3) the Paleozoic continental seas were never deep, and most of them very shallow, and (4) the surface of the continents is unstable and in Paleozoic ages was subjected to frequent more or less

local differential oscillations of level. Much other evidence of a similar nature will be found in succeeding parts.

EARLY RICHMOND TRANSGRESSION

For the first of these instances I have selected the Fernvale Richmond, a shale and limestone formation rarely exceeding 25 feet in thickness. Often the shale is absent when the limestones come together into one or more beds aggregating 2 to 5 or 6 feet in thickness. In its typical expression the Fernvale is limited to areas west of the Cincinnati axis.

Whether followed directly by Niagaran, Devonian, or Mississippian deposits, this thin limestone formation is present, except in very local elevations, wherever the sea of the time can be shown to have extended. Where it is absent the adjacent margin of the formation usually wedges out by overlap, the proximity to a shore being further indicated by increase in proportion of clayey matter.

On the west flanks of the Nashville dome, also elsewhere, it has been possible to establish approximate boundaries of baylike indentations to which the Fernvale is confined. Being filled with highly characteristic fossils, the bed is easily recognized. It has been studied at numerous outcrops around the southern and western flanks of the Nashville dome. In a northerly direction it has not been positively identified beyond Wilmington, Illinois, where it outcrops on the west limb of the Kankakee axis. On the east and southern flanks of Ozarkia it is nearly always found where beds of Mohawkian age were deposited, and in places it overlapped these so that it rests on much older pre-Ordovician rocks. Further, it is recognized in the Arbuckle uplift of Oklahoma as a 2 to 3 foot bed at the top of the Viola limestone by exactly the same lithologic and faunal characters that mark it in southeastern Missouri. In many places it is succeeded by a dark shale (the Sylvan) that can be shown to be a southward extension of the Maquoketa of Iowa.

In the bluffs of the Mississippi south of Saint Louis and north of Riverside the bed can be followed for miles. Here it rests unconformably on the peneplaned Kimmswick limestone, which is middle Mohawkian in age. At one point (between Sulphur Springs and Spencer Station) the Fernvale is succeeded by 16 to 25 feet of Maquoketa shale, and this by a variable bed of sandstone regarded as the initial deposit of the Kinderhook limestone. One-half mile south the Maquoketa has disappeared, bringing the Fernvale in contact with the Kinderhook. In the next two miles any one of several of the lower ledges of the Kinderhook—yes, even the Keokuk—may rest on the Fernvale. The most significant fact is that the Fernvale limestone is no thicker—it is usually about

2 feet—where it is succeeded by the Maquoketa than it is where the Mississippian rests on it.

It has not seemed possible to decide whether the exceedingly soft Maquoketa shale originally extended over all the known Fernvale areas. In my opinion it did not; but the point is not of material consequence. The astounding fact remains that erosion during an emergence extending through nearly the whole of two periods, the Silurian and Devonian, failed to remove a bed of limestone less than 5 feet thick! And this is not a unique case. The Mississippi Valley and other areas of Paleozoic interior seas are full of such instances. The Fernvale one is used to illustrate the proposition of exceedingly slight erosion only because it is so easily and positively demonstrable.

LATE RICHMOND SUBMERGENCE

The extraordinary extent of the late Richmond deposits affords even more instructive features than does the early Richmond Fernvale limestone. This late Richmond horizon, so far as known, never exceeds 25 feet in thickness. It is characterized by an association of corals, bryozoa, and brachiopods that may be recognized instantly. Because of the presence of the genera *Halysites*, *Heliolites*, *Calopœoia*, and *Favosites* it has frequently been identified as Niagaran. Hall, relying more on the Ordovician aspect of some of its brachiopods, referred to it as a Hudson fauna. This fauna and presumably stratigraphic horizon has been found on Saint Josephs Island in Lake Huron, in the Mississippi Valley to the north and south of Saint Louis, in the Big Horn Mountains of Wyoming, in Colorado, in Utah, in Manitoba, in the Eureka district of Nevada, in New Mexico, and in the Franklin Mountains near El Paso, Texas. Some of the corals and the most peculiar of the bryozoa occur in the upper Lyckholm of the Baltic section; also in the lower part of the Anticosti group in the Bay of Saint Lawrence. Apparently the same fauna has been found by Mr. Kindle in the Seward peninsula of Alaska. There is some evidence tending to show the presence of the Atlantic phase of this fauna near the top of the Richmond in Kentucky and Indiana, but on this point I prefer not to take a definite stand.

At Thebes, in southern Illinois, the bed holding this *Calopœcia* fauna rests on the eroded surface of the Girardeau limestone; in Lincoln County, Missouri, where it is found in the Noix oolite, on Maquoketa shale; in Lake Huron, on lower Trenton; in Manitoba, Wyoming, Colorado, Utah, Nevada, New Mexico, and Texas, locally on earlier Richmond deposits, but more commonly on typical Galena. Clastic matter occurs in the bed only as calcareous mud seams between layers of pure

limestone. Both the limestone and the shale are commonly reddish in color. The fossils, too, often exhibit evidence of wear on a beach or in very shallow water.

As to the beds succeeding this late Richmond horizon, they vary in age from early Niagaran to Mississippian. The latter sequence occurs in the Big Horn Mountains, and is perhaps more common in the far western localities than the Silurian succession. A fact of great significance is that this late Richmond bed has been recognized in every detailed section containing middle Ordovician rocks in the far west that has been brought to my attention.

SLIGHT EROSION OF INTERIOR SILURIAN AND DEVONIAN LANDS

The succeeding Silurian and early Devonian rocks of west middle Tennessee present similar evidence of slight erosion of adjacent contemporary lands. The Nashville dome seems to have been an island of considerable size during this time, its eastern shore extending beyond the present outcrop of Ordovician rocks. During the Niagaran its western part subsided gently, but not continuously, the advancing sea leaving a locally visible record in the overlapping sediments. Following the Louisville limestone, which is late Niagaran, the sea retreated, the final Silurian deposits being more local in occurrence than the earlier beds of the period. These late Silurian deposits in west Tennessee, like those in the Cumberland basin in Maryland, were marine, while apparently contemporaneous Cayugan deposits of more interior areas (western New York, Ohio, Michigan) were in part at least non-marine.

With the beginning of the Devonian the sea began once more to advance. This is shown by overlapping Helderbergian deposits. The edges of these Silurian and early Devonian overlaps are so well preserved that their thickness may be measured in places by inches. Thin wedges of late Onondaga follow the Helderbergian at only a few points, the usual succession on the west and south sides of the Nashville dome being Chattanooga shale on Helderbergian or older beds. Most of the exposed Ordovician, Silurian, and early Devonian areas in Tennessee appear, therefore, to have been raised above the plane of marine sedimentation during the Onondaga and such considerable parts of the time scale as intervened between the Onondaga and the local representative of the Chattanooga shale. The middle Tennessee representative of this shale, including the Hardin sandstone, I regard as corresponding somewhat imperfectly to the Cleveland shale, the Bedford shale, the Berea grit, and the Sunbury shale of the Ohio section.

The Chattanooga shale, which transgresses the edges of the preceding

Devonian and Silurian overlaps, is usually underlain by a thin, more or less phosphatic sandstone. The siliceous clastics of this sandstone could not have been derived from the Nashville dome, since none of its surface rocks were capable of supplying such material. Its character is such that only the Ozarkian land to the northwest, where the Saint Peter and older sandstones were locally under tribute in Devonian time, is suggested as the probable source. Besides, the clastics derived from the Nashville dome during this long period of emergence, as is positively indicated by the exceedingly slight erosion of the Fernvale and Niagaran rocks, must have been almost negligible in quantity.

INSTANCE OF SLIGHT EROSION IN THE BIG HORN MOUNTAINS

Perhaps an even more convincing instance of slight erosion during long periods of emergence and non-deposition than those already cited is the contact of middle or late Mohawkian deposits and upper Cambrian in the Big Horn Mountains of Wyoming. None of the elsewhere intervening Ozarkian, Canadian, and early Ordovician formations being well represented in any of the Rocky Mountain areas east of the Great Basin, it seems out of the question to assume that they were deposited there and subsequently removed prior to the great Ordovician transgression. The trend of all lines of evidence respecting these intervening deposits is that their respective seas never covered much of the Rocky Mountain area. The late Cambrian sea, on the contrary, is well known to have transgressed widely in the far and middle west. Hence, according to collateral evidence, upper Cambrian deposits are to be expected in the Big Horn Mountains, while on the same kind of evidence the absence of the other formations is justly ascribed to non-deposition. Following this conclusion, the important fact concerning the contact referred to is that the top of the Cambrian in the Big Horn Mountains is strictly correlatable with the upper beds of the Cambrian in Missouri, Oklahoma, Texas, and the upper Mississippi Valley, where the zone is overlain by Ozarkian or Canadian deposits. The real significance of this fact is appreciated when we remember that the limestone and dolomite formations deposited elsewhere in the time represented by the hiatus between the upper Cambrian and the Mohawkian in the Big Horn Mountains have an aggregate maximum thickness of over 12,000 feet.

LATE ORDOVICIAN EROSION IN THE MISSISSIPPI VALLEY

Perhaps the greatest pre-Pennsylvanian erosion of interior Paleozoic formations was in the closing stages of the Ordovician. South of Hannibal, Missouri—in the southern half of the Mississippi Valley proper—it

began long before the close of the Trenton. On the east and south flanks of Ozarkia the late Black River Kimmswick, a crystalline limestone of earlier date than the Galena dolomite proper, is the last of the Ordovician deposits. On these flanks it is immediately succeeded or overlapped by the Fernvale limestone, which is regarded as one of the first deposits of the Silurian submergence. In Lincoln County, Missouri, where the Fernvale seems absent, the Kimmswick is succeeded by Maquoketa shale, which, as has been noted, locally succeeds the Fernvale farther south in the valley.

Rather generally, in the upper Mississippi Valley, the Galena dolomite is succeeded by the Maquoketa shale. That the top of the Galena proper—that is, without the Dubuque limestone—is never younger than the Trenton limestone is, I believe, shown conclusively by its fossil contents. That the Maquoketa, which overlies it, is not older than lower Richmond is proved (1) by the occurrence of a faunal zone, characterized by *Clidophorus neglecta* and other small mollusks at its base at Dubuque, while the same zone is found *above* the Fernvale limestone south of Saint Louis, and (2) by the position of the Fernvale in middle Tennessee, where it *overlies* the Leipers formation, which is the local representative of the Maysville group of the Cincinnati section. The validity of these correlations can not be questioned. The disastrophic evidence in each case is no less definite than is that of the fossils.

Clear evidence of this late Ordovician erosion is seen in the bluffs of the Mississippi between Saint Louis and Cairo. Here the fact of base-leveling of the Kimmswick limestone is shown positively by (1) a study of the contact of this limestone and the overlying Fernvale limestone, and (2) the uniform thickness and composition of the Fernvale considered in connection with the wide extent of the overlap of this formation.

In the vicinity of Thebes, Illinois, and Cape Girardeau, Missouri, the Kimmswick includes at the top some 5 to 30 feet of crystalline limestone, containing *Echinosphærites, Comarocystites,* and other peculiar fossils. This bed overlies another, easily recognized by the abundant presence of a large *Receptaculites* (*R. oweni*). Every outcrop in this area shows a different horizon at the top of the Kimmswick. That the Kimmswick at Thebes originally included even higher beds than are known there is indicated by later Trenton chert, found in broken down pre-Fernvale caverns.

Going northward from the cape the Kimmswick and Fernvale dip out of sight beneath younger formations. They come to the surface again between Establishment and Plattin creeks on the north limb of the syncline, but the outcrops in this area are not favorably situated for detailed study. In the next syncline, which is shallower, these formations are

most favorably exposed in quarries and cuttings along the Iron Mountain Railroad, which here follows the west bank of the river. Observations were made at frequent intervals between Riverside and Wickes Station below the mouth of Meramec River.

At Rattlesnake Creek and Bushberg the top of the Kimmswick is formed by the Receptaculites oweni bed. One-fourth of a mile south, in the Glen Park quarry, the Fernvale rests on a lower bed. Then there is a long bluff to Grand Glaize Creek, showing how the contact descends still farther. Between Sulphur Springs and Kimmswick there is a minor syncline, in which the contact rises a few feet. In the last exposure, above the town of Kimmswick, the contact seems to have descended again. In 5 miles of almost continuous exposure the Fernvale cap maintains its thickness of a little more or less than 2 feet.

On the flanks of the Nashville dome the Kimmswick, with characteristic lithology and fossils, indicating the upper part of the formation, has been observed at only one point, namely, in the southwestern part of the circumference, near Aspen Hill, Tennessee. Here it is over 40 feet thick, and followed in turn by the Hermitage, the Bigby, and the Catheys, all three of Trenton age. The contact with the underlying formation is not seen, but there is no reason to doubt that the Kimmswick at Aspen Hill rests either on the Carter limestone, which is commonly succeeded by the Hermitage, or on a wedge of Lowville. The latter formation, though usually absent on the west side of the dome, is believed to reach the vicinity of Aspen Hill by overlap from the south.

Deposits of Cincinnati age (Eden and Maysville) are generally wanting on the south and east sides of the Nashville dome, but along the west and north a good development of the upper division is indicated by the Leipers formation of Hayes and Ulrich. The Eden is unknown along the Cincinnati axis south of central Kentucky, though the upper member of this group probably extended well on toward the border of middle Tennessee. Crustal movements had caused the withdrawal of the Ordovician sea from the greater part of the accessible area previously covered by it. Shrinkage at the same time caused elevation of Appalachia and accentuation, with slight general depression, of the Appalachian Valley troughs, the latter opening the way for the Utica invasion of the Northeastern States to Cincinnati.

Where the full Utica follows the Trenton the transition is more often gradual than abrupt. However, at Cincinnati, which point was reached by only the last of the Utica deposits, there is clear evidence of erosional unconformity between the Utica and the middle Trenton on which it rests. In middle Tennessee, where the emergence at close of the Trenton

continued through the Utica and later stages of the Eden, the elevation must have been very broad and without marked local flexing. Erosion of the Catheys prior to the submergence of the west and north flanks of the dome by the late Cincinnatian or Leipers sea is indicated chiefly by the local absence of some of the upper layers. There are no clastic deposits worth mentioning at the contact of the Leipers and Catheys. The plainest feature of the physical evidence of the hiatus between the two is the unquestionable landward overlap of the Leipers. The most western exposures of the contact contain a number of clearly distinguishable beds in the lower part of the Leipers that are entirely absent in the Nashville hills; and on the south flank, as near Fayetteville, the Leipers is represented by only the uppermost member, the lower Platystrophia bed.[7]

LATE CINCINNATIAN EROSION IN NORTHERN APPALACHIAN AREAS

While the erosion of the interior areas during the closing Cincinnatian stage of the Ordovician was so gentle that the process is not obviously indicated by resulting clastic deposits, erosion of a more vigorous type prevailed in northern Appalachian regions. This is indicated by land or delta deposits of sandstone (Oswego, "red Medina," and Juniata sandstones) in New York and central Pennsylvania, in which no trace of marine fossils has yet been found. The fineness of the sand indicates a low gradient for the streams that carried it, but the thickness of the deposits, which in Pennsylvania locally aggregate over 2,000 feet, shows that the contributing area was large and its elevation considerably greater than the average for the continent at that time.

EROSIVE AGENCIES RELATIVELY INEFFECTIVE IN NEGATIVE AREAS

Reasoning from observed thicknesses and reputed original extent of clastic deposits, it is supposed rather generally that at various times of emergence great sheets of sediments were removed by erosive processes. Geologists holding this view naturally assume also that the continental seas were of great extent and often of very considerable depth; that they endured with merely local interruption, from one period to another—as, for instance, from the beginning of the Cambrian to the close of the Ordovician. Further consequent assumptions (1) that the local absence or thinning of sediments of certain ages signifies their complete or partial removal in the process of peneplanation, and (2) that the geographic variations observed in the composition of fossil faunas and in the character of marine deposits are due to local changes in contemporaneous

[7] The upper Platystrophia bed, indeed none of the members of the McMillan formation forming the top of the Cincinnati section, has been recognized in middle Tennessee.

physical conditions similar in expression and effects to those prevailing on the earth of today.

As must be plain from preceding statements, indeed from the whole tenor of the present work, I can not subscribe to these views. In the first place, the continental seas were but seldom large and never deep, nor did they endure through many geological ages. On the contrary, they were limited in extent and subject to frequent oscillations and withdrawals. Next, the geographic changes in nearly contemporaneous fossil faunas are due less to local physical conditions than to original peculiarities of the faunas of the oceanic basins from which the different continental seas happened at the time to draw their organic supplies. Finally, I find no warrant for the assumption that great sheets of marine deposits have

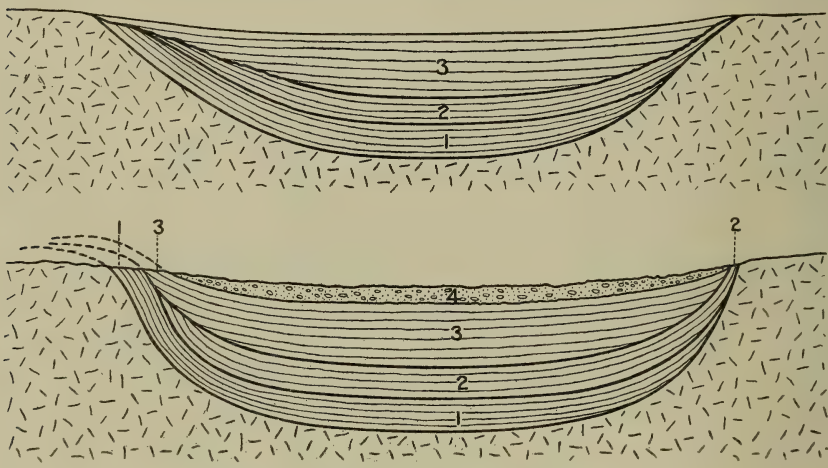

FIGURE 2.—*Illustrations of marginal Erosion*

The sketches illustrate marginal erosion of deposits in a warped or slightly folded basin, with subsequent deposition of a conglomerate partly composed of material derived from the exposed edges of the lower beds. Bed 2 should have been represented as reaching the surface at the left of the lower sketch.

been entirely eroded away. It seems rather that nearly all surface degradation of considerable magnitude has ever been confined to the positive areas. This commonly involved the edges of the marine sediments, which overlapped the flanks of such upwarped areas, and sometimes also the thinning sheets covering them were removed. But over the broader negative areas, particularly in the Paleozoic, erosion processes have always been comparatively negligible in their effect on consolidated deposits.

It is not my intention to deny that great elevations have been reduced at times to baselevel. Indeed, as is indicated by occurrence of clastic deposits in certain sections, I think this occurred repeatedly in the same

area. What I do wish to say is that this erosion was practically always confined to the periodically rejuvenated upwarped areas, and that the marine or lake deposits were similarly confined to and laid down over each other in the same more or less limited superposed basins. With each of the successive upwarps the beds which were first deposited on their flanks become more and more inclined, and as the older formations are rarely seen except near the axis of the arch the contacts naturally are more distinctly unconformable here than farther out in the basins. Obviously, again, the more extreme the uplifts the less time is required to cut through the upturned and relatively thin overlapping edges of the formations. Besides, other factors being equal, erosion is facilitated in increasing ratio to the amount of relief. Hence in estimating the time value of a gap in the record we are not justified in concluding that because an overlying conglomerate contains pebbles derived from formations aggregating, say, 10,000 or 20,000 feet in thickness, the gap represents a time interval of sufficient length to remove a corresponding thickness of deposits. Statements implying erosion of such magnitude have been frequently made in discussions of the Laramie problem—as, for instance, by Cross—who in one of his papers says, "In the pebbles of the Arapahoe . . . is the record of the slow erosion of 14,000 feet of strata." [8]

What amounts actually were removed from the "positive" areas we have no satisfactory means of determining. When no remnants are preserved, apparently the only clue lies in the thickness and lateral extent of the deposits which they contributed to adjacent "negative" areas. A point that should be made in this connection is that whereas the proposition of permanence of positive and negative areas, together with the hypothesis of small, oscillating continental seas, reduces the hitherto assumed total amount of erosion, it reduces also the amounts required to fill the limited basins. Besides, we know well that only a small proportion of the clastic sediments extends far beyond the heavily laden troughs immediately adjacent to areas of folded and contorted pre-Cambrian rocks, which, after all, contributed by far the greater amount of such material.

PERIODIC REVIVALS OF EROSION PROCESSES

Assuming that baseleveling was in progress through all the ages, it yet seems that at certain recognizable times the process was strongly revived. Local accelerations and revivals, especially in the submarginal areas of the continent, occurred at frequent and not easily classified intervals. But the greater revivals, implying deformative movements of broader,

[8] W. Cross: Post-Laramie deposits of Colorado. Am. Jour. Sci., vol. xliv, July, 1892.

probably world-wide significance, seem more readily classifiable. Referring on this occasion only to the Paleozoic, they took place at what I conceive to have been rhythmically recurring intervals, corresponding essentially to the systemic divisions of the stratigraphic column as drawn in the revised classification to be proposed. Each of these systemic periods was preceded by deformative movements, resulting in a general elevation of the continent and consequent great, as a rule almost complete, withdrawal of the continental seas, and each begins with the first succeeding advance of the sea over the now sinking, more or less planed, floor of the continental basin.

CYCLES OF EROSION AND DEPOSITION

Under the conception[9] of relatively short periods of active diastrophism, resulting in large continents and high lands and longer periods of relative quiescence during which the lands were reduced, the well established idea of cycles of erosion should be reflected in corresponding cycles of deposition. In fact, however, detailed study of the sediments in continental basins shows that in these at least the concordance between the two processes is far from complete. On reflection, it must soon be clear that such concordance is possible only in constantly submerged areas like the oceanic basins. In the oscillating and frequently emerged continental basins, on the contrary, widely prevailing agreement in this respect is highly improbable. When something of the kind is suggested in these basins it usually proves that the accord is fortuitous or more apparent than real and normal. Still a few apparently real, though local and neither complete nor typical, instances of cycles of deposition in continental seas are known. Many limestone formations, too, begin with thin accumulations of sandstone and shale, but these, though essentially typical of the process, are not usually referred to under the term cycle of deposition. As defined by Newberry[10] and commonly applied, it refers to a transition in character of sediment, typically ranging from sandstone to shale, then to limestone, and ending with a return to fine clastics, under supposed continuous submergence extending through the whole of an era, a period, or an epoch. I question if this ever occurred in any continental basin. That subsequent remarks may not be misunderstood, I should add that the fourth, or "retreating sea," stage is the least important, and that only the first ("shore") and the third ("open sea") stages are really essential.

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[9] As recently defined by Bailey Willis, in Science, issue of Feb. 18, 1910, pp. 246-251.

[10] John S. Newberry: Cycles of deposition in American sedimentary rocks. Proc. Am. Assoc. Adv. Sci., vol. 22, pt. 2, 1874, pp. 185-196.

Among the more notable and commonly cited examples of cycles of deposition is (1) that beginning with the Cambrian quartzites and ending with the Ordovician limestones and shales, (2) beginning with the Medina and ending with the Niagaran limestones and Salina mixed deposits, and (3) beginning with the Oriskany and ending with the Middle Devonian Onondaga limestone and Hamilton shale. Taking them at their face value, it must be admitted that these instances are not altogether satisfactory from the theoretical standpoint. The cycles are certainly not coordinate, and none fits a major unit of the stratigraphic column accurately. The petrologic sequence, too, is not the same in different areas, nor are the correlated beds always even approximately contemporaneous. But if the contemporaneity of the deposits concerned in the cycle is not to be considered, if the feature of coordinateness may be disregarded, and especially if the continuity of the process of sedimentation covered by the cycle is not a factor of vital importance, then these are good examples. But what useful purpose could such cycles serve in working out a systematic history of earth diastrophism? Indeed, when carefully analyzed according to present knowledge of stratigraphy, these and other great cycles fail so badly that we may well doubt the possibility of using the prevailing conception of cycles of deposition in framing a satisfactory scheme of stratigraphic classification. Judiciously modified, the principle may attain considerable taxonomic value.

Coordinated and classified, the cycles would probably assist materially in fixing the boundaries of many stratigraphic units. They would help also in the elucidation of the diastrophic history of the continents. They might be arranged somewhat as Willis has attempted to do (op. cit., page 247) into "grand cycles" corresponding to the eras of the time scale and into several lower grades of "epicycles." But the cycles are too uncertain in development, distribution, and possibilities of interpretation to enable us, solely on the basis of their physical manifestations, to discriminate truly between the cycles of major and minor import. Other means of correlation are essential. Apparently their classification is possible only in the light of the fossil organic record.

PALEOZOIC CYCLES

For any one to cite Cambro-Ordovician sedimentation as a single cycle of deposition, which is comparable with the early Silurian and middle Devonian cycles, is to expose great ignorance of the actual sequence of Eopaleozoic deposits. The lower Cambrian usually begins with rather coarse clastic deposits. In the Appalachian Valley these are sometimes followed by shaly middle and upper Cambrian beds, and these again by

enormous deposits of calcareous matter. But, taking the whole sequence as now worked out, we find that the middle Cambrian was locally preceded in the Appalachian Valley and in the Cordilleran basin by great beds of lower Cambrian limestone. In such areas, then, the essential parts of a "cycle" had been accomplished before the close of the lower Cambrian and another begun with the middle Cambrian. This second cycle also was completed long before the close of the Cambrian in the southern Appalachian Valley, where it began with the Rome sandstone and ended with the first limestones of the Honaker group. The third cycle, poorly indicated in the Appalachian region, but well developed in Missouri, began in the latter region with the Lamotte sandstone and closed with the dolomites and limestones of the Bonneterre and Elvins formations. With the last the Cambrian period, as here defined, also terminated.

The fourth coordinate cycle has a nearly typical development in northeastern New York, where it began with the Potsdam sandstone and ended with the Little Falls dolomite.

Though the stages of these four cycles are developed in a reasonably typical manner in the areas mentioned, they are scarcely recognizable in contemporaneous deposits elsewhere. This seems true of all the cycles, of whatever grade; and herein lies the greatest of the difficulties encountered in applying the criteria of cycles of sedimentation to stratigraphic taxonomy. The point is especially well illustrated by the fourth cycle, which, as said, is satisfactorily expressed in New York, but not even suggested by the sequence of deposits in the corresponding part of the Knox dolomite.

The discrimination of the succeeding Paleozoic cycles of similar rank is often much more difficult. A late Ozarkian one is indicated in Missouri by the Roubidoux sandstone and the Jefferson City dolomite. Those of the Canadian, however, are all as yet very obscure, and perhaps can not be determined in America except by assuming that the clastic stages are confined to the marginal provinces and the limestone stages to the Appalachian and other interior provinces. Of the Ordovician cycles we recognize the first in the Saint Peter-Joachim series in the Mississippi Valley, but the sequence of deposits making up the succeeding series of this system seems nowhere divisible into corresponding distinct cycles of sedimentation. Like the Canadian, they are represented in the Atlantic province almost entirely by shales; in the Appalachian and other interior provinces by either limestones only or by limestones below and shales above. The Silurian is like the Ordovician, having a fairly typical cycle at its base (comparable to the Saint Peter-Joachim cycle and closing

with the limestone at the top of the Clinton), but showing almost nothing of the kind in its middle and later deposits. The Devonian differs in that it begins with a limestone series, has a fair "cycle" in the middle, and closes with shales and so much sandstone that Newberry, the father of cycles of deposition, thought it advisable "to consider the Portage sandstones . . . as the true base of the Carboniferous system." The Waverlyan often begins with a sandstone (Hardin in Tennessee, Sylamore in Arkansas), followed in turn by shale (Chattanooga) and limestone (Louisiana to Chouteau), but the upper, Osagian, series is lithologically too uniform to suggest a typical cycle. In the Tennessean also cycles corresponding to its series divisions are very poorly indicated, and the same is to be said of the Pennsylvanian. For these post-Ozarkian systems therefore the ordinary criteria of cycles of sedimentation (detrital sediments passing into limestone) fail rather generally. Probably the coarse clastics of the typical cycle may, in the case of these failures, find a satisfactory substitute in the fine and relatively sparse detrital material included in calcareous shale and argillaceous limestone. Or, when the series consists almost entirely of mechanical sediments, cycles may be established according to the grade of fineness to which they have been reduced. But the prospect seems on the whole rather discouraging.

Considering that there are few and locally no limestones to complete the cycles of the sedimentary record in the Appalachian and Atlantic troughs east of the great valley, and often no sandstones with which to begin them in the broader basins of the more inland areas, it is clear that the local manifestation of cycles of erosion and deposition is dependent on conditions having no readily determinable bearing on stratigraphic taxonomy. If generally and regularly developed, or even if each important cycle had been adequately expressed in some, however local, but accessible situation, they might constitute an excellent basis of classification. But as it is, their possible use for this purpose is largely defeated, or at least rendered uncertain by the frequent oscillations and emergencies to which the areas of accessible record of marine deposition have been subjected from the beginning of geologic time. So far as they can be clearly determined they should be employed, but at their best the function of cycles of deposition in stratigraphic taxonomy is corroborative and not initiative.

PRESENT AND PALEOZOIC CONDITIONS BRIEFLY COMPARED

The gradational processes and agents at work today, also the conditions under which they operate, are essentially the same as in many of the preceding geological ages. As today, so in past ages there must have

been great local variation in erosional processes and results. The only real difference is that in the submergent stages, to which our knowledge of the pre-Cenozoic periods is largely confined, the size of the continents, and especially the average relief of the lands, was generally much less than now. Therefore, while degradational agencies in the periodic highly emergent stages probably were active enough and occasionally perhaps comparable in vigor and results to those of the present time, those working on the relatively low lands prevailing in the intervening submergent phases must have been correspondingly inferior in both respects. It will be understood, of course, that I am referring only to the continental areas, whose record is accessible and more or less studied. Concerning the extreme marginal lands, the early record of which is scarcely decipherable, these probably were frequently high and as often reduced by erosion. Speculative contributions to their history will be attempted in following sections (see pages 435 to 477). Despite the easily established fact that in several important respects present conditions along our sea shores are very different from those prevailing in and adjacent to the continental seas of the past, it is common practice among geologists to insist on a strict accounting of the old according to the familiar features of the present. We know, for instance, that the character of the near-shore bottom of the Atlantic varies rapidly and greatly from place to place. Here we see a clean sand beach, near by a fine mud bottom, and not far away the shore is strewn with great boulders torn from a massive cliff. Similarly extreme, yet today very ordinary, variation of shore conditions seems to have been very rare, not to say impossible, in the Paleozoic epicontinental seas. Their shores were rarely or never precipitous, and the broad interior lands washed by these seas were often so low that the small clastic matter derived from them exerted a scarcely appreciable effect on the character of the deposits along hundreds, yes thousands, of miles of shoreline. The latter extreme in uniformity of sediment is shown by the Lowville, a thin middle Ordovician limestone formation, covering nearly 500,000 square miles of territory. Naturally, the best examples of geographic persistence of lithologic units are found among the limestone formations, but we have also *black* shales and *blue* shales, and even sandstones, that spread over great areas.

And yet the latest editions of such excellent text books as Dana's Manual (pages 398-399), Geikie's Textbook (pages 655-656), and Kayser's Lehrbuch (II, pages 6 and 7) contain statements that can not fail to impress the student with the belief that precisely similar variability of bottom and shore as occurs in the ocean basins of today prevailed also in the continental seas of all geological periods. It is not that these

statements are wholly untrue in theory and fact, but that, in the absence of sufficient qualifications, they imply much greater diversity than ever occurred in the interior continental areas. I object to them not only on this account, but for the reason that such assertions logically suggest difficulties in the way of determining the true chronological sequence, hence in the way of practical correlation that either do not exist at all or are much less formidable than they are made to appear. Even such broad statements as "many a sandstone in New York and Pennsylvania is of contemporaneous origin with a limestone in the Ohio and Mississippi valleys" (Dana, page 398) are exaggerated if not actually untrue. Most of the deposits thus referred to are either too thin or too obviously local to be taken into account or they are not strictly synchronous, so that the cases wherein such a statement is justifiable are really *few*, not "many."

Of course, I have no wish to deny that "in all periods sand-beds, mud-beds, clay-beds, pebble-beds, and limestone-beds have been *simultaneously* in progress over different parts of the globe." I object only to the indiscriminate application of this truth to *all parts* of the globe in *all ages*. While admitting that similarly diverse sedimentation occurred at all times on the globe, it yet seems clear that such diversity prevailed over the whole globe, or some large part of it, only at times of great emergence like the present. On the other hand, when and where the general relief of the lands was low, diversity of conditions determining the local character of deposits must have been correspondingly less, and in the broad continental seas it seems never to have been very great, being indeed considerable in these only occasionally along the shores of newly submerged land masses. Considering, finally, that the sedimentary record accessible and known to the stratigrapher is almost confined to these submergent phases, it will be clear that in the practical application of the science the "difficulties" in correlation due to lateral variation of deposits is much less than is commonly supposed.

Reviewing the conditions that we may justly infer to have prevailed in past geologic ages, the present differs sufficiently from the average to be called abnormal. Depending on organic evidence, mild climates prevailed throughout the northern hemisphere during a large majority of the distinguishable ages of which the marine record is preserved and accessible in the continental basins. Regarding the intervening ages, some of which must have been long and perhaps very different in climatic and other features, too little is yet known of these to permit their adequate consideration. Including, therefore, only the more or less well known ages in our comparison, the present seems abnormal (1) in the extreme differentiation of climatic zones and (2) in the highly emergent attitude of

the continents with respect to the level of the sea and the consequent restriction of marine habitats favoring the development of shallow-water faunas. Both factors tend to extraordinary diversification in environment, hence in distribution and specialization of faunas and floras. Both, again, but more especially the second, tend to increase the normal irregularity in production and distribution of clastic matter, thus causing further localization in faunas. The oceanic currents, too, probably follow very different paths today from those which carried certain Paleozoic pelagic faunas (especially graptolites) almost if not entirely around the globe. At certain times the two American continents must have been separated, permitting the representative of the Gulf Stream to pass through the opening. It is not my intention to discuss the oceanic currents of past ages. Too little is known about them. For present purposes it suffices to say that since the form and intercommunications of the Paleozoic oceans were often very different from their present derivatives, it is reasonable to infer that the currents which traversed them were correspondingly different.

In view of the known and probable differences between conditions prevailing now and in the past, I maintain it is unreasonable to insist on agreement with the present standard in determining Paleozoic conditions.

Oscillatory Character of Continental Seas

General Discussion

Any one who will undertake a course of critical comparison of numerous sections of rocks laid down in the various continental seas must inevitably reach the conclusion that the old surface was exceedingly unstable with respect to sealevel and subject to oft-repeated differential movements and warping. The causes and character of these movements are to be discussed in a later part of this work. Here it will suffice to say that the differential movements are indicated by abrupt local or general changes in the character of sediments, by imperfections in the stratified record at one locality which are partly or wholly supplied by the record in another place, by the sudden extinction of, say, an Atlantic fauna in a given area and the subsequent occupancy of the same area by a Pacific or a Gulf fauna, and by other more or less competent criteria. Simple vertical movements, if there ever were such, are indicated by more equable general advances and retreats of the strandline. The mass of the continent as a whole always bore a definite and constant relation to the oceanic areas, and in so far the land areas may be called stable; but in the respective attitudes of different parts of its surface to sealevel and

to each other it was exceedingly unstable. The seas were usually small and patchy, and slight tilting of the surface in one direction, then in another, necessitated continual change in their boundaries, and frequently complete withdrawals. Numerous comparative studies more or less clearly illustrate this instability of the continental surface. It is indubitably shown on the flanks of the old interior uplifts—the Cincinnati, Nashville, and Ozark islands of the Paleozoic seas. Convincing evidence indicating similarly uneven changes of the strandline is to be seen also around the shores of the Adirondack and Wisconsin peninsulas These are rather fully described in Part II, and others more incidentally in a series of papers in course of publication. That the more continuously submerged Appalachian Valley was likewise, perhaps even to a greater extent, subject to such oscillations, is shown by the following discussion of the Chambersburg limestone.

MIDDLE ORDOVICIAN OSCILLATION INDICATED BY THE CHAMBERSBURG LIMESTONE IN SOUTHERN PENNSYLVANIA [11]

Chambersburg limestone in the Chambersburg-Massanutten basin—Character and stratigraphic relations.—The very different composition of the Chambersburg limestone in the Chambersburg-Massanutten basin and in the parallel Mercersburg trough affords one of many striking illustrations of the instability of the floor of the continent during the middle ages of the Ordovician. In the typical sections, between Chambersburg and Greencastle, Pennsylvania, the formation has a thickness ranging from 500 to 600 feet at the former town to over 800 feet at the latter. The lower 150 to 200 feet of the last figure varies rapidly in thickness, being very thin or absent at Chambersburg and northward from that point. It is absent also to the south of Greencastle, at Pinesburg, Maryland, and at Martinsburg, West Virginia; nor was it observed at Winchester, Virginia, but at Middletown and Strasburg, Virginia, its upper part is again represented by 100 feet or more of partly cherty limestone. The variation is due to warping and overlap, the basal part, which contains *Tetradium cellulosum* and other characteristic Lowville fossils, having been observed only in the vicinity (2 to 5 miles north) of Greencastle. The upper part of this lower member of the formation is correlated with the cherty upper member (Leray) of the Lowville of New York.

Following this variable basal member is the lower Echinosphærites bed (40 to 50 feet), which carries besides, especially at Strasburg, Virginia.

[11] Since this was written additional information respecting the Chambersburg limestone, especially field relations of the formation and lists of fossils, has been published in Folio No. 170, Atlas, U. S. Geological Survey. Whatever discrepancies may be found in the two accounts the present is to be regarded as the newer.

a brachiopod and bryozoan fauna highly suggestive of the upper part (Phylloporina bed) of the "Black River shales" or Decorah formation of Minnesota and Iowa.

The lower Echinosphærites bed is overlain by the Nidulites zone. This averages approximately 200 feet in thickness, but reaches nearly 300 feet in the vicinity of Greencastle and Marion, Pennsylvania, where an unusual amount of fine clastic matter in most of the beds is partly responsible for the great thickness of the Chambersburg at these localities. As a rule the Nidulites bed contains the heaviest ledges in the formation; but again the Greencastle section includes equally thick, or even heavier, beds near the top of the formation that elsewhere in the basin seem to be absent entirely. The Nidulites bed was easily recognized by its characteristic fossil in every full section of the formation observed in this basin. It and the overlying Christiania bed, together more than 600 feet thick, represent an age in the general time scale between the top of the Black River and the base of the Trenton, in New York.

Following the Nidulites bed, the section again shows great local variations. At Chambersburg the remaining upper part of the formation consists of limestone ledges alternating with generally thicker beds of shale, the whole belonging to the Christiania bed and aggregating approximately 270 feet. In a few inches of rock at the extreme top occurs a rather poor representation of the Sinuites fauna, which invaded from the west, and a few feet beneath this the upper Echinosphærites and principal Christiania zone. These upper fossil zones are still recognizable 6 to 8 miles up the valley. In the opposite direction, say 2 to 6 miles southwest of Chambersburg, they are especially rich in organic remains. Farther south, however, the fossil zones are gradually obscured in the great expansion of the upper beds of the formation already noted as occurring in the vicinity of Greencastle. Here the beds above the Nidulites zone and to the base of the Martinsburg shale vary in thickness between 300 feet and fully 500 feet. Very heavy beds of dark gray, sparsely fossiliferous limestone, weathering chalky and locally more or less arenaceous, make up the greater part of the upper 100 to 200 feet in the thickest sections. At Pinesburg, Maryland, the corresponding portion of the formation is thinner and consists mostly of shale, the general aspect and composition of the whole formation at this point being essentially the same as at Chambersburg itself. At Martinsburg, West Virginia, where the Lowville member is absent, the lower Echinosphærites bed, 15 to 20 feet thick, and the Nidulites bed, 300 feet thick, the next or uppermost bed of the formation (Christiania zone) is only about 20 feet thick. At Strasburg, Virginia, the Nidulites bed, a solid

limestone 207 feet thick, is followed by a 40-foot bed of argillaceous gray limestone and calcareous shale containing the second appearance of *Echinosphærites,* with many brachiopods and other fossils characterizing the Christiania fauna. The faunal association is so closely like that found 2 to 6 miles south of Chambersburg that the contemporaneity of the two occurrences seems unquestionable.

Basal member of the Martinsburg formation.—Overlying the Christiania bed the Strasburg section shows about 300 feet of thin-bedded, very argillaceous, light gray limestone and calcareous shale, referred to the Martinsburg and passing at the top apparently gradually into darker true shales. No fossils were seen in this impure limestone except in the relatively shaly part that lies 10 to 30 feet above the base. Several layers here were filled with *Corynoides* cf. *gracilis* and *calycularis, Climacograptus spinifer, Leptobolus insignis, Schizocrania filosa, Dalmanella testudinaria*? and *Caryocaris* sp. nov. This association compares rather well with the fauna at Van Schaick Island, New York, listed by Ruedemann,[12] and probably is the same as one found by Weller at Branchville, New Jersey.[13] Possibly this 300-foot bed is equivalent to the 200-foot bed of heavy-bedded limestone and shale found at the top of the Chambersburg limestone at Greencastle, Pennsylvania, but, in the writer's opinion, it is a subsequent deposit. At both localities, it is true, the next succeeding shale contains *Triarthrus becki, Trinucleus concentricus,* and *Caryocaris,* with other less diagnostic fossils. Also that these same crustacea occur in a similar dark shale just over 120 feet of argillaceous limestone and shale at Martinsburg and again at Chambersburg, only here it is found directly over the Christiania bed. But the respective faunas of the heavy-bedded limestone at Greencastle and the 300-foot bed of argillaceous limestone at Strasburg are essentially different. The 12 species found in the former are all either the same or closely allied to species found in the Christiania bed or lower, while those observed in the Corynoides bed are all distinct and more suggestive of Trenton and so-called Utica species. These facts indicate (1) a withdrawal of the waters of the basin at the close of the Christiania bed, except in a local depression in the vicinity of Greencastle, in which the remnant was retained long enough to accumulate massive calcareous sediments to a maximum thickness of about 200 feet; (2) a gradual resubmergence of the basin with northward diminution of calcareo-argillaceous deposits that, as stated, diminish from 300 feet at Strasburg to 120 feet at Martinsburg and are

[12] R. Ruedemann: New York State Museum. Bull. No. 42, 1901, p. 524.

[13] Stuart Weller: New Jersey Geological Survey. Rept. on Paleontology, vol. 3, 1903, p. 52.

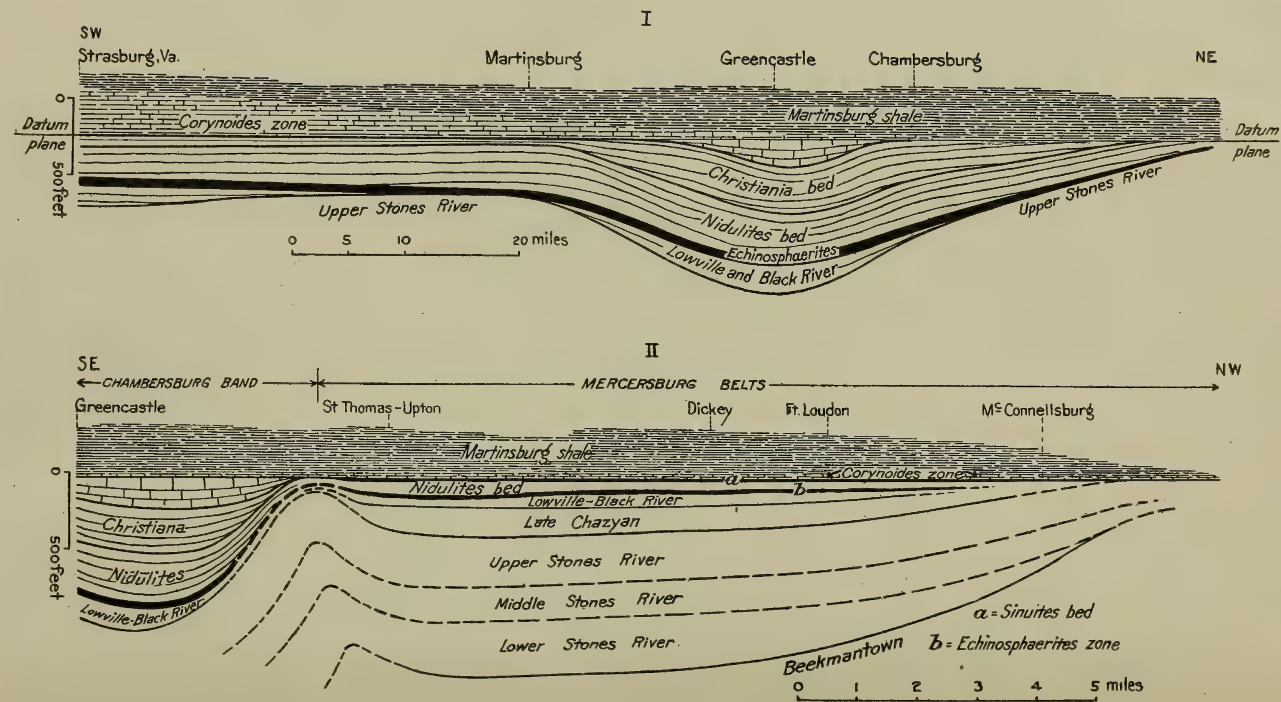

FIGURE 3.—*The Chambersburg Limestone*

I. The Chambersburg limestone in the Massanutten-Chambersburg trough, showing longitudinal variation in thickness and composition between Strasburg, Virginia, and some undetermined point 15 to 20 miles north of Chambersburg, Pennsylvania.

II. Shows variations of the Chambersburg limestone in a northwest direction from Greencastle to McConnellsburg, Pennsylvania.

generally wanting in the basin north of the Maryland-Pennsylvania line, and (3) a final, more extensive submergence, bringing in *Caryocaris, Triarthrus,* and *Trinucleus.* (See figure 3-I.)

Chambersburg limestone in the Mercersburg (*Pennsylvania*) *bands*—Character and stratigraphic relations.—Sections of the Chambersburg limestone belts west of the Chambersburg-Greencastle-Martinsburg-Strasburg band, while differing considerably among themselves, agree in certain dominant features, wherein they differ from the more eastern phase of the formation above described. It will be remembered that in the eastern belt the Chambersburg includes four easily distinguishable faunal zones, namely, (1) Tetradium cellulosum, (2) Echinosphærites, (3) Nidulites, and (4) Christiania, followed in order by the Sinuites, Corynoides, and Trinucleus zones of the Martinsburg. Further, that the formation there begins often with the lower Echinosphærites bed, but locally, as west of Marion and near Greencastle, Pennsylvania, and at Strasburg, Virginia, 100 to 200 feet of compact Lowville limestone is intercalated between that zone and the top of the underlying upper Stones River. In the Mercersburg bands, as the more western representation of the formation may be conveniently called, the same zones, except the Christiania, are recognized, the first and the second, however, more definitely than the third (Nidulites). A striking difference is that the Lowville Tetradium cellulosum zone, instead of being at the base, is here above the middle of the formation, the lower 100 to 175 feet being made up of a subcrystalline limestone containing a fauna requiring its correlation with the upper Chazy of New York, the Murat limestone of Virginia, and the Holston marble of Tennessee. It is to be noted further that even with this additional lower member the whole formation is much thinner than in the Chambersburg-Massanutten basin. Regarding the thickness, there is to be added that in the middle belts of the Mercersburg basin all the members are thicker than in the belts to the east and, more especially, those to the west. In the most westerly band both the Nidulites as well as the Christiania zone may be absent entirely.

The Lowville horizon, which in the Appalachian as well as the more interior regions is nearly always marked by *Tetradium cellulosum,* is commonly recognizable in the Chambersburg limestone bands of the Mercersburg area. This horizon is well exposed in a railroad cut just south of Fort Loudon, but the succession of the beds is somewhat confused by faulting. The rather coarsely crystalline Caryocystites bed, which underlies the Lowville, contains, aside from a few species peculiar to the bed, a disconcerting mixture of upper Chazy and Lowville-Black River fossils.

Its age may be early Lowville, but for the present it is placed at the top of the upper Chazy member. The contact between the Caryocystites bed and the next following exhibits unmistakable evidence of interrupted sedimentation. The first 6 inches or so of the Lowville consists of irregularly bedded, dark gray, rather compact clayey limestone, which fills slight irregularities in the top surface of the lower bed. It is full of a slender *Beatricea, Helicotoma planulatoides,* and other fossils, while parasitic bryozoa and the expanded bases of *Cleiocrinus* are attached to the eroded surface of the bed beneath. All of the fossils suggest late Lowville, but the *Beatricea* is of exceptional importance for correlation purposes, as it is usually present in this area, and occurs also in the Champlain Valley to the north and in central Alabama to the south in beds regarded as of the same age. This thin basal deposit is followed at Fort Loudon by 8 or 9 feet of bluish, subgranular and suboolitic limestone, certain seams of which are filled with *Leperditia* and other ostracods. Then comes an 8-foot bed of pure dove limestone, resembling oolite when moistened, but really a very fine conglomerate. This contains *Tetradium cellulosum, Leperditia,* and *Helicotoma.* It is the last of the undisturbed sequence shown on the east side of the cut. In another near-by exposure a darker, subgranular, massive limestone, 12 feet thick, overlies the dove limestone, and is followed by about 15 feet of thin-bedded and shaly layers corresponding to the displaced ledges shown on the west side of the southern end of the cut. Fragments of the characteristic fossil of the zone, *Echinosphærites,* occur near the top with *Cleiocrinus grandis.* These with other fossils procured from the last bed indicate a position between the Black River and the basal part of the Trenton limestone.

Above the Echinosphærites bed the Fort Loudon section shows 36 feet of fine grained, cobbly weathering dark limestone, correlated on lithological grounds and because of its stratigraphic position with the Nidulites bed. This is followed by 1 to 2 feet of black, partly shaly, crinoidal limestone referred to the Sinuites bed. Here, however, the *Sinuites* is rare, the most striking and commonest fossil being *Trinucleus concentricus.* This, the first of the beds referred to the Martinsburg formation, is succeeded by about 40 feet of hard, platy argillaceous limestone interbedded with black slaty shale. The last bed is correlated with the argillaceous limestone and calcareous shale (Corynoides bed) overlying the Christiania bed at Strasburg, Virginia, and Martinsburg, West Virginia, at which places, however, it is much thicker—respectively 300 feet and 120 feet.

Blue Spring section.—Comparing other sections of the Chambersburg limestone in the Mercersburg bands with the Fort Loudon section, above

described, we find in an exposure of a western belt at the Blue Spring, 3 miles southwest of Mercersburg, the usual subcrystalline limestone at the base, terminating above with the Caryocystites bed. This is succeeded by a Lowville-Black River representative only 2 to 4 feet thick. Several of the lower layers of this bed are crowded with *Beatricea gracilis,* while others above are filled with *Leperditia.* Next comes 12 feet of granular uneven-bedded dark gray or blue limestone, representing the Echinosphærites bed, then about 55 feet of earthy thin-bedded, compact dark-blue limestone, weathering cobbly in lower half and shaly in upper, and in which organic remains are very scarce. This is followed by drab calcareous shale. In Licking Cove, 2 miles farther southwest, the section is essentially the same except that the upper beds are much better exposed. In the absence of fossils it is very difficult to decide whether the 55-foot bed is really the correlative of the 36-foot bed at Fort Loudon. If it is, then shale deposition began here earlier than usual in the Chambersburg limestone belts. More likely it corresponds to the 40-foot bed overlying the top of the Chambersburg in the Fort Loudon section, and hence that the Nidulites and Sinuites zones are wanting in the Blue Spring and Licking Cove sections.

The Dickeys, Pennsylvania, section.—A good exposure of the middle beds of the formation occurs 4 or 5 miles southeast across the strike from Fort Loudon in a railroad cut just north of Dickeys station. Overlying the Caryocystites zone, which is easily recognized, is a bed 34 feet thick, of massive, light to dark bluish gray, compact limestone containing *Beatricea* and *Tetradium cellulosum* in abundance. As the Leperditia bed does not occur in this section, and the following beds seem to be referable to the Nidulites zone, it would appear that this 34-foot bed represents chiefly the hiatus at the base of the Lowville in the Fort Loudon section. Over it in the Dickeys cut come 85 feet of bluish gray fine-grained limestone, rather thin and irregularly bedded, and weathering cobbly in the lower and upper parts. The middle part is comparatively heavy bedded and mottled with clay, giving the weathered surface a reticulated aspect. Although the most characteristic fossil was not seen—indeed it has not been observed in any of the Mercersburg bands—this bed is correlated with the Nidulites zone because its upper part contains a number of fossils so far found only in association with *Nidulites favus* in the Massanutten basin. The Echinosphærites horizon may be included in the lower part but was not recognized. Next comes a massive bed of dark bluish gray crinoidal limestone, 6 feet thick, containing characteristic fossils of the Sinuites bed. The overlying beds are not well shown, but appear to be in general character as in the Saint Thomas section next described.

Chambersburg limestone section near Saint Thomas, Pennsylvania.—A full section of the Chambersburg limestone in the most easterly of the Mercersburg belts was observed 2 miles south of Saint Thomas. Next above the Caryocystites bed comes first 18 feet of granocrystalline, in part minutely conglomeratic, bluish gray limestone, from which no recognizable fossils were procured. Then 1 foot of similar limestone full of a new *Leperditia,* and above this the Beatricea bed, 15 feet thick, minutely granular in texture and containing clayey pebbles in the upper part. This last is succeeded by 53 feet of rock like that at Dickeys referred to the Nidulites bed. It is overlain by the usual bed of granular limestone, but here the early Trenton Sinuites fauna of the latter is uncommonly well preserved and prolific. The Sinuites bed is followed by 31 feet of nearly unfossiliferous calcareous black shale and thin black limestone, terminating above with a thin zone often filled with *Corynoides gracilis* and other graptolites. Beyond this the bed grades upward into the typical dark shale of the Martinsburg. The sharpest lithologic break in the upper part of this section, as also in the Fort Loudon and Dickeys sections, occurs at the top of the Sinuites bed. Ample grounds, therefore, exist for referring the argillaceous limestone above this bed to the Martinsburg. Respecting the Sinuites fauna, it should be said that it is locally present in the Chambersburg-Greencastle band at the base of the shale and just above the zone in which the Christiania fauna is best developed. In the section at Chambersburg this is at least 250 feet above the top of the Nidulites bed, while west of Marion the interval is 400 feet or more. Evidently it succeeds an important interruption of deposition, and for this reason it is referred to the Martinsburg rather than the Chambersburg.

Résumé of differences between the Chambersburg and Mercersburg belts.—Briefly recapitulated, the differences between the Chambersburg limestone sections in the eastern basin and those in the Mercersburg trough are (1) the presence in the latter of 150 feet or more of granular limestone containing an upper Chazy fauna never seen in the former, (2) whereas in the Massanutten basin Chambersburg limestone deposition, beginning locally with as much as 200 feet of Lowville limestone, seems to have progressed steadily to the close of the Nidulites zone, in the Mercersburg basin, on the contrary, oscillation caused (*a*) interruption at the close of the upper Chazy portion, (*b*) varying delay in Lowville submergence, and (*c*) local discontinuity prior to the Nidulites invasion, (3) while over 200 feet of Nidulites limestone and from 40 to 300 feet of interbedded shale and limestone, with the typical Christiania fauna, and 0-200 feet of massive limestone, with a modified Nidulites and Christiania beds fauna, were being laid down in the Massanutten

basin, near Greencastle, Pennsylvania, only 0-90 feet were deposited in the corresponding time within the Mercersburg area, and (4) the fossil, *Nidulites favus,* is always present in its proper horizon within the Massanutten basin—likewise the overlying Christiania fauna—but neither has been seen in the Mercersburg belts.[14]

DISPLACEMENTS OF THE STRANDLINE

Stratigraphic overlaps—General discussion.—The numerous oscillations mentioned, and the many more described in succeeding parts of this work, naturally suggest corresponding local or general stratigraphic overlaps. Obviously, too, an overlap suggests preceding sea withdrawal and cessation of marine deposition in the areas thereby emerged. Though a period of sea transgression without such immediately preceding retreat is conceivable, I have met with no instance that may be unqualifiedly described as meeting the requirements. The break that marks the base of the overlapping sediments also defines the top of the next underlying deposits, and the break between them would not be recognized if sedimentation had not been interrupted; and discontinuance of deposition ordinarily means sea withdrawal. It was only in the relatively deeper parts of the continental seas, in which, on account of the persistence of the downwarps of the surface, the older deposits are usually buried beneath the newer, deposition may often have continued during the minor sea withdrawals. In these covered areas, then, the breaks in sedimentation observed in regions where the older formations are exposed to view doubtless are less, and in many cases the record there may be much more continuous and possibly unbroken. The general truth of this statement is established by innumerable deep wells driven in the synclinal spaces between the Paleozoic anticlinal arches and domes. That most of the Ordovician and Silurian formations thicken under cover of later deposits to the west and south of the Adirondack uplift has long been recognized, and a similar increase in volume of deposits is shown on the flanks of all of the interior areas of frequent uplift. That this phenomenon is due to frequent emergences alternating with more gradual submergences, hence to overlap of deposits in an alternately retreating and advancing sea, seems incontrovertible.

[14] Considering these striking provincial differences, the propriety of using one and the same name, Chambersburg limestone, in the two areas may well be questioned. I do not think that two distinct names are needed, but there should be some method of qualifying the term in use, so that either phase might be referred to as desired. Perhaps the best and easiest way would be to eliminate the upper Chazy beds from the formation, in which case the difference between the two areas would not be greater than usual in overlapping formations. (See pages 386-390.)

In the course of my field studies I have perhaps paid more attention to the investigation of overlap phenomena than to any other feature of stratigraphic geology. Nearly every formation, and in many cases the well marked members of formations, found outcropping on the flanks of the old gentle uplifts of the interior flat of the North American continent, exhibit unquestionable evidence of overlap structure. A similar structure pertains also to the formations in the folded Appalachian region, only here the sedimentary record is more complete and the easily recognizable gaps are usually separated by thicker beds and have a correspondingly inferior time value. However, those that have been observed in the Appalachian region, although commonly representing a much shorter period of time, are no less distinctly marked than are the corresponding hiatuses in the thinner sections of the interior areas. Detailed correlations between the thick Appalachian sections and the thinner, less complete records exposed on interior uplifts like the Cincinnati dome, enable us to reach a fair conception of the relative importance of the numerous gaps in the latter. Obviously, the hiatuses which are as sharply defined in the relatively complete Appalachian Valley sections as those seen in more interior areas like the Cincinnati uplift must be of much greater taxonomic value than those which are entirely unrecognizable, or but obscurely indicated, in the former.

Progress of overlaps interrupted and modified by emergent phases.—Sea transgressions over continental areas probably never progressed uninterruptedly through the whole of a period and certainly never continued into and through the succeeding period. There is therefore no basis in fact for the rather commonly accepted view of a continuous, gradually increasing submergence of the American continent, beginning with restricted early Cambrian troughs and ending in a great lime depositing Ordovician sea, that is supposed to have covered the greater part of the continent. Neither is there any ground for the proposition not long ago submitted by Grabau[15] of great "progressive overlaps," the first of which began with the Cambrian and, spreading in various directions in different parts of the continent, continued to advance to Ordovician time, while another began with the Devonian "Black Shale" and continued to the Tennessean. As is rather fully shown in discussing the effect of currents in continental seas (pages 362-374), the continents were never subjected to such long continued and gradual encroachments of the sea nor to the great and deep submergences believed in certain quarters. In fact the

[15] Types of sedimentary overlap. Bull. Geological Society of America, vol. 17, 1906, pp. 567-636.

continental seas were as a rule comparatively limited in extent and, further, their waters were repeatedly and more or less completely withdrawn into the great oceanic basins. The evidence on which these statements are based may be gathered from numerous observations recorded in this work. It has not seemed worth the space to repeat it here except such parts as bear directly on the principles under discussion.

Detailed paleontologic and stratigraphic investigations relating to the hitherto supposed long enduring general encroachments of the Paleozoic seas is proving that these were interrupted, and the direction of the movement of the strandline reversed, at certain times that seem to have been essentially contemporaneous for the whole world. These general reversals, resulting, as I believe, usually in very great if not complete emergence of the continents, occurred at least at the close of each of the great periods. Indeed, the evidence is so abundant and convincing that I can not doubt that not only the systemic boundaries, but also those of series and perhaps of groups can be drawn in Europe as in America at actually corresponding breaks in the marine sedimentary record. There is no question as to the gaps in the record—experience has shown that their detection is merely a matter of intelligent search in good exposures. The only grave difficulty lies in their proper correlation and in the determination of their respective taxonomic values.

Of course, little that is final can be done along these lines if "matching" of faunas alone is relied on. Since learning that the faunas of the several oceanic basins are very distinct, and that each may continue with little modification through long periods, as has been shown in discussing recurrent species and faunas, also that the great changes in local successions of fossil faunas is more commonly due to overlapping of oceanically distinct faunas than to evolution of the preceding fauna, simple matching of species and genera has become but a small, and by itself a far from competent factor in a modern paleontological correlation. As the prevailing classification of formations in America and Europe is based almost entirely on this inadequate old method, and as the faunal criteria have not been consistently employed in all cases, some changes in definition of systems and series is to be expected. It is highly probable, too, that some of the most important boundaries have been overlooked, or if observed that their significance has been misinterpreted and underrated. Properly determined intercontinental correlations therefore are likely to result in some hitherto unsuspected equivalences, and the surprises are scarcely less when the correlations concern provincially distinct formations on the same continent. Some of the latter are brought out in the correlation charts of Part III.

As will be shown in a later section, the Cambrian submergence was interrupted by movements at the close of the lower Cambrian and again at the close of the middle series. Later the waters of the succeeding late Cambrian (Saint Croix) invasion apparently were completely withdrawn from the North American continent at the close of Cambrian deposition. The frequently asserted continuity of sedimentation in continental basins from the Cambrian into the Ozarkian (including Saratogan), or Beekmantown, or Ordovician, or whatever the next succeeding deposits may have been called, in reality did not occur. The supposed transition is based on mistaken correlations of Ozarkian rocks in New York, and more especially in the deep Appalachian and Cordilleran troughs, with older deposits in the Mississippi Valley, Oklahoma, Texas, and the Rocky Mountains, that I regard as representing the closing stage of the first Paleozoic system in America—in other words, of the American Cambrian system as defined in this work.

The fossiliferous Ozarkian, so far as I can learn, begins everywhere in America with the first introduction of the typical Dikelocephalus fauna. Of course, the immediate ancestors of this trilobite lived before, but their remains seem not to occur in accessible deposits, being apparently absent and probably later than the youngest of the beds referred to the revised Cambrian. In the Mississippi Valley typical representatives of the genus are accompanied by a well developed molluscan fauna that before the close of the middle Ozarkian series (Saratogan) spread widely in America. Wherever I have had an opportunity to study the beds there was never any trouble to find evidence of an hiatus between the Ozarkian and the underlying upper Cambrian when this was present, and the final deposits of the latter always exhibited criteria of extensive shoaling and subsequent emergence.

The widely effective Saratogan submergence, with which Ozarkian deposition began in New York, affords excellent examples of overlaps. The deposits of this second series of the Ozarkian are rather well developed in the Champlain Valley but thin rapidly northward by overlap in Canada. They overlapped also all around the Adirondack island, though tilting of this dome is indicated about the middle of Saratogan time that prevented deposition on the western and northern flanks during the later (Little Falls dolomite) half of the epoch. The great Knox dolomite, the larger part, if not the whole of which, as developed in Copper Ridge and at Knoxville, Tennessee, represents the New York Saratogan in the southern Appalachian region, likewise overlaps northwardly to extinction in the western folds of the great valley. In the most western of these it extends as far north as Martinsburg, Pennsylvania. In another, more east-

ern trough, it apparently wedges out not far north of Lexington, Virginia. The Saratogan part of the Knox being rather generally absent in the eastern fourth of the valley of east Tennessee, the series doubtless overlapped also in that direction, but the fact is not readily demonstrable in the field because the thin edge of the formation is covered by overthrust faulting. Finally, clear evidence of Saratogan overlapping has been observed in the upper Mississippi Valley, but details remain to be worked out. The advance of the Saratogan sea, though locally reversed at times by warping of the continental surface, seems on the whole to have been nearly continuous. The first notable interruption occurred at the close of the Little Falls dolomite deposition in New York. This was followed by considerable warping and extensive sea withdrawal, so that the succeeding late Ozarkian geographic pattern is strikingly different from the preceding Saratogan phases. So far as known, New York and Canada and, excepting perhaps southwestern Virginia, the whole Appalachian Valley remained above sealevel during the later Ozarkian submergence, which seems to have been confined almost entirely to the interior areas of the United States. It left considerable deposits in Missouri and Arkansas (chiefly the Jefferson City dolomite) and possibly extended northward in the Mississippi Valley to Minnesota and Wisconsin. The evidence of the latter, however, is not entirely satisfactory. (For other Ozarkian overlaps see pages 547 to 549.)

The Ozarkian was followed by another great withdrawal of the sea. Even where the succeeding Canadian limestones attain a thickness of over 4,200 feet, as in central Pennsylvania (see the Bellefonte section in Part III), the contact with the underlying Ozarkian rocks presents unmistakable evidence of an emergence gap. Also in southeastern Missouri and northern Arkansas, where early Canadian deposits rest on a warped and eroded surface of upper Ozarkian, the contact between the two is unconformable and exhibits such undeniable evidence of intervening subaerial conditions as old sinkholes and superficially decomposed and subsequently recemented cherty dolomite.

Less widely recognizable, though not unimportant, breaks in sedimentation occur in the Canadian, but the next great emergence marks the boundary between this new system and the revised Ordovician. And so it goes on to the end of the chapter. Instead of very long enduring, continuously progressive overlaps, geologic history, as I see it, indicates frequent interruptions and reversals of the tendency of the sea to submerge the lands.

Minor interruptions indicating relatively local movements.—Besides the submergences which define the major divisions of the stratified column, there were very many minor, or incomplete, sea withdrawals. Perhaps they should be called local, but I hesitate to do so because it is only the criteria of sea retreat that vary in degree of development and distinctness from place to place. The boundaries are nearly always there, though they may be relatively inconspicuous in proportion to the locally diminished gap in the record. These minor gaps are being more and more clearly recognized in stratigraphic investigations, and as the geologist searches them out and studies their relations to gaps in other sections their number is being greatly increased.

Detailed stratigraphic studies of this kind are being carried on with striking success by European paleontologists engaged on Mesozoic rocks.[16] In America we have not yet attained such refined results, though this is due mainly to the absence or scarcity in most of our Mesozoic deposits of fossils, like the semipelagic ammonoids, with sufficiently complex structure to permit the detection of slight mutations. Perhaps the highest degree of refinement in correlation so far attempted in America is that in an as yet unpublished work on the Ordovician rocks of the Cincinnati geanticline. The principal results of these studies are outlined in succeeding pages of the present work (pages 416 and 526), where they are cited to illustrate simple and differential oscillations ("tilting") and correlation by lithologic criteria. (See also Correlation Tables.)

Somewhat different examples of overlapping formations are the Silurian deposits in small narrow embayments on the west flank of the Nash-

[16] Since this was written S. S. Buckman has published an interesting paper on "Certain Jurassic (Lias-Oolite) strata of South Dorset" (Quart. Jour. Geol. Soc. London, lxvi, No. 261, Feb., 1910) that may be cited as an excellent illustration of advanced modern methods in correlation. A few sentences quoted from this paper will bring out the results of principal interest in this connection:

"The deposits of one place correspond to the gaps of another. Therefore many localities have to be placed together to produce the full tale of the Inferior Oolite. The very local distribution of Inferior Oolite species often means that strata of particular dates have only been preserved in a few favored localities. . . . The beds of the 'Inferior Oolite,' in a restricted sense, have now been divided as deposits of about twenty-two successive dates or hemeræ. The total for the whole of the Jurassic would not be more than about eighty-five, or perhaps, on an extended scale, a hundred hemeræ. . . . One can hardly view the few feet of Inferior Oolite limestone at Burton Bradstock, about 15 to 20 feet say, and imagine that it represents an interval of time equal to a quarter or a fifth of the whole Jurassic period—a time during which thousands of feet of strata were laid down. But this is because we do not allow sufficiently for the gaps. . . . The Upper Lias part of the Junction Bed of Down Cliffs, Chideock (Lower or pre-*striatulus* Toracian), is a very condensed, imperfect epitome in 20 inches of about 180 feet of strata on the Yorkshire coast, and of very much more when allowing for gaps. . . . Between the *bifrons* layer and the *striatulus* layer of the Junction Bed there is occasionally a 2-inch layer which is all that represents some 250 feet of deposit in the Cotteswolds—so that about two feet of Junction Bed was formed while a thickness of some 550 feet was being deposited elsewhere."

ville dome (see page 307) and the Yellville to Osagian formations in the larger embayments of the southern shore of Ozarkia. The Yellville especially offers interesting features (see pages 421 and 667) in that the distribution of the successive members or zones of the formation is not at all the same in the several embayments.

Frequency of alteration of submergent and emergent conditions indicative of smallness of Paleozoic movements of land areas with respect to sealevel.—The mere fact that the sea advanced many times in geologic history over continental areas, and that the submergent stages alternated with a like number of times when emergence of lands prevailed, argues strongly for the smallness of the vertical element that is responsible for the displacement of the strandline. I do not refer to the comparatively limited "positive" areas, whose tendency has always been toward relative uplift and which doubtless rose to considerable and, at times of unusual diastrophic activity, perhaps to great altitudes, but to the broader "negative" areas which were commonly, or at least likely to be, inundated in the submergent phases. Regarding these negative areas only a slight general displacement of the sealevel would effect the submergence or emergence, as the case may have been, of wide stretches.

Wide areas characterized by negative tendencies, like that between the Appalachian folds on the east side and the Cincinnati axis on the west, comprise nearly parallel bands having the essential anticlinal structure of positive areas. Sometimes these have formed important, though rarely complete, barriers, against which marine sediments overlapped from either side. Rather generally, too, the location of "pools" of petroleum and natural gas have been controlled by them. However, as tectonic features, they have been subordinate to the negative troughs flanking them and were dragged down with these and included in broad geosynclines. In the case mentioned there are many minor folds besides at least two that were important at times. One of the latter, the Carter axis (see map, page 293), is a marked structural feature in eastern Kentucky, having formed the western shore of several Paleozoic seas. The other is the Helderbergian barrier, which limited the western extent of certain Appalachian formations. The Appalachian Valley, with its subordinate anticlines and troughs, and each of the latter with a different section, is a more striking example of a compound syncline, but on account of its complicated structure and stratigraphy it is less easily described. However, a fair idea may be gathered from the description of the Chambersburg limestone in southern Pennsylvania (pages 321 to 329) and from the discussion of southern Appalachian formations in Part II (pages 412 and 543 to 571) and Part III.

Similarly the larger regions, whose general tendency is positive—anticlinoria, like Appalachia, Laurentia, and, to use a smaller example, Ozarkia—these all include subordinate areas of negative tendencies. When such regions are submerged it is these subordinate depressions that receive deposits first and which retain them longest. Whether subsequently the warps were merely accentuated, as in the case of Laurentia and Ozarkia, or strongly folded, as in Appalachia, I question if the sedimentary evidence of such submergences has in any case been entirely removed from the structural depressions. However, as between gently warped and folded areas, entire removal would seem to be much more likely in the former than in the latter.

Bearing on paleogeography.—The foregoing considerations have an important bearing on paleogeography. The recognition of certain areas as having *positive* tendencies and the discrimination of others as being *negative*, and therefore more likely to be submerged than the former, eliminates much of the initial uncertainty. Except, possibly, in strongly folded regions, where complications arise through faulting and unequal resistance of formations to compression and erosion, the structural depressions of today inherited their general features from similar depressions of preceding ages, and this rule pertains to the small synclines as well as to the great oceanic basins. But the attitude of synclinal areas with respect to sealevel varied from time to time and is altogether relative. If the surface of a continent had been repeatedly and uniformly warped so as to bring it partly beneath sealevel, the geographic features at such times would have been much the same in each, and the resulting expressions would be highly suggestive of a relatively stable earth and the operation of simple sea filling and of other eustatic processes. But the movements, while approximately uniform in the matter of kind and areas affected, were not so in amount of displacement, either as regards locality or time of occurrence. Comparing the frequently changing geographic patterns, it does not seem possible that the displacement of the strandline is due solely to a raising of the sealevel, whether by sea filling, land attraction, or equatorial bulging. On the contrary, the evidence brought out by a close study of the distribution of marine sediments shows conclusively that the strandline moved in obedience to locally varying oscillations of the surface of the lithosphere, and that submergences and emergences are due to body deformations of the earth rather than to any other known cause.

Sometimes an area that under conditions of general subsidence was commonly submerged remained above sealevel, while other relatively de-

pressed spaces which, on account of their location were as a rule dominated by the prevailing positive tendency of adjacent areas, were but rarely overflowed. However, whether submerged or not, the essential structural relations of adjoining areas remained always the same.

The great Canadian shield—Laurentia—seems to be a region that has not been entirely submerged since the beginning of the Paleozoic, and submergences of interior parts of it occurred only at times of such low average altitude of the continent as prevailed during the middle Ordovician, middle Silurian, middle Devonian, and middle to late Cretaceous. Small to large remnants of the deposits of these ages are now found only in the gentle downwarps of the shield. Though probably still an archipelago during even the greatest of the submergences mentioned, I do not doubt that the deposits accumulated at such times, especially the Ordovician and Silurian, were originally much more extensive than we now find them. Even admitting that their erosion was exceedingly slow in the downwarps, at least to the Cretaceous, we may reasonably assume it to have been more active on the flanks of the upwarps. Considerable parts of the Paleozoic sheets probably were removed from these more exposed situations, and even more may have been carried away in the Pleistocene, during which time the region was repeatedly subjected to active ice and water erosion. The probable fact that every Paleozoic marine formation that was ever laid down on this shield is preserved in part at least in its downwarps, especially if we consider the "positive" tendency of the region, argues strongly against the assumption that thick deposits were ever completely removed from any large area. For this and other reasons I maintain that we are justified in interpreting the total absence of a given formation in any considerable structural basin as signifying absence of the corresponding sea.

However, in the making of a paleogeographic map the investigator must take into account the possible channels through which faunas might reach certain areas, and here we encounter the principal, if not the only exceptions, to the above rule. These channels may be buried, or deposition may have been prohibited in them by rapid currents; or, if they received deposits, these may have been on positive areas where they would be liable to rapid erosion in subsequent emergent stages. (See discussion of effects of currents in continental seas, page 362.) Positive information respecting the first condition is often acquired in boring deep wells. Thus, the drill has frequently established the presence, under cover of overlapping later deposits, of considerable beds, or even whole formations, of which no sign is to be seen in exposed sections. Occasionally the paleogeographer, reasoning from the known geographic occurrences

of a given fauna, may correctly anticipate the discovery of such buried channels by the driller. Such an instance is given on page 423, where thick Devonian and other formations, wholly absent in the exposed stratigraphic succession on the west flank of Ozarkia, are mentioned as being found in a deep well at Forest City, Missouri. It may be argued that the failure of these concealed formations to outcrop in Missouri is due either to removal of the deposits by erosion or that their deposition was prevented by current scour along a shore. For various reasons I can not admit either suggestion. As I see the case, it means only that the channel or basin to the northwest of Ozarkia was narrower at such times and the lands larger. As for the concealed formations themselves, they mean nothing more or less than overlapping sediments whose final stage fell short of stages attained in subsequent submergences.

Initial submergences often larger than succeeding invasions of same stage or period.—That the advance of the sea into the continental depressions, especially of the median areas, was probably never continuous through the whole or even the greater part of a geologic period is convincingly indicated by the fact that the advance in the early part of a stage often exceeded later invasions of the same stage. It is a fact, too, that the geographic pattern formed by the distribution of land and water areas in these later ages differed from that of the early phases generally not only in that the areas submerged were smaller, but more in that the seas were shifted partly or wholly into other basins. Body deformations, resulting in warping and differential oscillation of the lithosphere, the latter phenomenon to be later described under the designation "tilting," are primarily the cause of these differences in geographic aspect.

The idea is illustrated by the varying stages of the Ozarkian seas. Thus the early Saratogan, represented in New York by the Potsdam sandstone, elsewhere by either sandstone or dolomite, seems to have spread as widely in the United States as any sea of this period. In New York it is found on both the east and west sides of the Adirondacks, and corresponding beds are recognized in the Appalachian Valley, in Missouri, and in the upper Mississippi Valley. Now the passage from the early (Potsdam) stage of the Saratogan to the lime-depositing middle phase involved a geographic change. This is shown in New York by the restriction of the sea to the east and south sides of the Adirondack mass. There were marked changes, also, in the Appalachian Valley, where the waters retreated to the south and west; also in Missouri and in the upper Mississippi Valley, where considerable sea shifting occurred at this time. The new (Gasconade) distribution continued through a

long time with apparently no very important oscillations until the sea withdrawal preceding the last stage of the period. The latter suggests merely restriction of the Ozarkian sea, accessible deposits of this age, so far as known, being found chiefly or only in the Mississippi Valley.

The Canadian seas exhibit a more striking example of the proposition. In New York the earliest deposits of this period are found only on the west and south flanks of Adirondackia, while all later Canadian formations in the State are confined to the Champlain trough and its southern continuation. Both are well represented in the northern and middle divisions of the Appalachian Valley, but the upper is absent south of the Staunton axis. In the Mississippi Valley the period seems to be represented by its early to middle stages only, and the same is true of central Texas. But the later as well as the middle stages are well developed in western Texas, Oklahoma and rather generally in the Great Basin of the far west. Thus, it will be observed that while the early Canadian submergence simulated the geographic pattern prevailing during the middle stage of the Ozarkian, subsequent Canadian patterns differed widely.

Comparison of the Ordovician seas indicates a similar sequence of movements. The proposition holds, also, though not uniformly, for the succeeding Eopaleozoic periods. In the closing stage of the Ordovician decided restriction of seas occurred. The extraordinarily wide submergences of the interior areas of the continent which prevailed in the late middle Ordovician stages were almost entirely replaced by emergent phases in the Cincinnatian. Deposits of this age are practically confined in North America to the southeast of a line connecting the mouth of Ohio River and the north shore of the Gulf of Saint Lawrence, and the last of the truly marine Cincinnatian is known only from the Cincinnati dome.

The Richmond, to which age the typical Medina of the Appalachian region is referred, is regarded as beginning the Silurian. The oldest of the Richmond faunas—the Arnheim—invaded from the Gulf of Mexico and like the last of the Cincinnatian (McMillan) is found only on the flanks of the Cincinnati dome and on the west side of the Nashville dome. But before the close of the Richmondian the seas of this time had spread over the interior areas of the continent to an extent and in a manner closely simulating the great, though somewhat composite, early Trenton submergence. As is well known, the distribution of the middle and late Silurian deposits is much less extensive and, especially in the eastern half of the continent, very different.

The cause of the relative greatness and distinctness of the introductory submergences of most periods is twofold. In the first place, during the

intersystemic interval the general elevation of the interior area of the continent, which had been the primary cause of the draining of the seas of the preceding period, was in course of gradual reduction by continental creep, and this seems to have proceeded without much local warping through the early stages of the next period. At the same time the emerged surface suffered slight degradation. Finally, when the general subsidence of the interior plain reached the stage of submergence by marine waters, the new continental seas naturally simulated those of the preceding period in pattern and size. As stated on page 446, "continental creep" is ever opposed by "suboceanic spreading." In the course of the conflict between these and other factors the surface of the continent pulsates up and down, falling very gradually when the former is dominant and rising, particularly in decidedly positive areas, more impulsively when the latter prevails. In the case of the widely submergent introductory phase of the Silurian, as established by the extraordinary distribution of Richmondian deposits, the downward trend of the land was presently interrupted by an emergence. The last movement evidently began a series of warpings that, as "creep" once more prevailed, were sufficiently accentuated to cause wide differences in the extent and general pattern of ensuing Niagaran continental seas. It appears then that the early submergences of these periods simulated preceding submergences chiefly for the reason that warping of the interior areas was largely delayed to later stages of the new period.

Regarding the periods in which the accessible early depositional stages are neither larger nor conspicuously different from subsequent stages, it is thought that these indicate preceding intersystemic intervals of non-accessible deposition and continental emergence of longer duration than usual. In other words, that the epoch corresponding, for instance, to the introductory stage of the Silurian was in these cases included in the intersystemic interval whose record is inaccessibly buried under the marginal shelf of the continent. Or it may be merely a peculiar phase of the rhythm, something like this being suggested by the fact that the periods whose first series of accessible deposits is of relatively small extent are those (Ordovician, Tennessean, and Cretaceous) which immediately precede the great revolutions. In favor of the former interpretation there is to be urged the fact that the physical as well as the faunal break between the Waverlyan and the Tennessean, and perhaps also between the Comanchean and the (upper) Cretaceous, is greater than between the other systems of their respective eras. Indeed, we might say that the accessible sedimentary record of these systems was delayed to the second stage—that is, deposition in the continental basins began

after the first considerable warping of the period. To illustrate with an example, the Tennessean section would thus seem to contain no strictly marine series corresponding in relative position within the system to the Richmondian at the base of the Silurian, or to the Helderbergian at the base of the Devonian. On the other hand, the Waverlyan probably contains no beds of a date relatively so late in the history of this period as the Cincinnatian in the Ordovician and the Cayugan in the Silurian. The Ordovician system differs radically from all the others, because the stage which corresponds to the Richmondian of the Silurian and the Helderbergian of the Devonian, namely, the Stones River, is preceded by an earlier depositional stage—the Saint Peter. Other aspects of this idea are discussed in following sections of this chapter, and more particularly in Part III, pages 603 to 608.

The vertical displacement of the strandline and the relief of continental land-masses—General discussion.—While abundant and reasonably decisive data bearing directly, or by inference, on local and general relief of the continents in past ages are readily procured, it is a much more difficult matter to reach satisfactory conclusions respecting the total vertical displacement of the strandline in any given age or period. The horizontal extent of the several submergences can be determined to within reasonable limits, and with the advance of detailed knowledge a near approximation of the truth seems attainable. But the horizontal element can bear no uniform proportion to the vertical factor of the displacement. Obviously the geographic extent of a submergence depends as much or more on the average relief of the land over which the sea is advancing as on the sum of the rise of the waters on the one hand and the subsidence of the land on the other. Thus, in times characterized by relatively great average relief of interior areas of a continent a given vertical displacement of the shoreline would result in less extensive submergence than in periods of lower relief. In other words, the submergence of an unwarped or peneplaned area, as, for instance, the surface over which the Richmondian transgressed, required much less of vertical displacement of the strandline than did the warped surface prevailing in the Black River and the Niagaran. Obviously, too, with similar rates of movement the sea transgressed the former more rapidly than the latter. (See pages 305, 367, 405, and 540.)

During the whole of the Paleozoic the relief of the interior areas of North America, and probably of all continents, is thought to have been very low. That this was so, at least as a rule in the Paleozoic eras, is convincingly indicated by the instances of very slight erosion in long emer-

gent intervals described on pages 305 to 313. Much greater relief, and consequently more active erosion, doubtless occurred in the marginal lands. This phase of the problem is discussed in considerable detail on pages 468 to 477.

Another pertinent thought is that even with equal averages of relief prevailing in two distinct ages the respective total vertical displacement of sea and land may be approximately the same in both, although in one the advance of the sea over the land was relatively insignificant, while in the other it attained great areal extent. In the former the submergent phase may have been preceded by a great emergence, involving the outer platform of the continent, while in the emergence preceding the latter the marginal shelf remained under sealevel to a corresponding extent.

That alternations of emergent and submergent conditions, of advancing and retreating seas, occurred in geologic ages seems incontestable. Indeed, I am of the opinion that marine sedimentation in the continental basins was very often interrupted because of retreat of the sea. Further, that complete or partial evacuations of the basins occurred not only at the close of every system, but also at frequent intervals during each of the periods. The view is based chiefly on the fact that even in the fullest sedimentary records now accessible the evidence of interrupted deposition is still clearly shown. Not only do we recognize in these more complete sections the breaks that have been determined in interior areas of frequent overlaps, but other discontinuities are found in beds rarely present except in such deep, more frequently submerged troughs as those of the Appalachian Valley. Abundant confirmative evidence, showing almost continual oscillation, sometimes continental in extent, at other times relatively local in visible effect, is presented in this work.

Discussion of illustrative diagrams.—After much study of these movements I have reached the belief that the volume of difference between the maximum rise and fall of the continents with respect to sealevel is approximately equal, or rather not greatly dissimilar, for all the periods except those immediately concerned in the great revolutions which terminate the eras. In these the vertical displacement of the strandline, also the average relief of the continents, seems to have been somewhat greater. The idea is illustrated by figure 4. As shown in diagram B, the line of the curve indicating the vertical displacement descends about as far beneath the datum plane of assumed average sealevel in the greatest submergence as it rises above it in the greatest emergence. The course of the curve in the case of the other systems is based on the best information available concerning Paleozoic geography. (See also pages 602-606.)

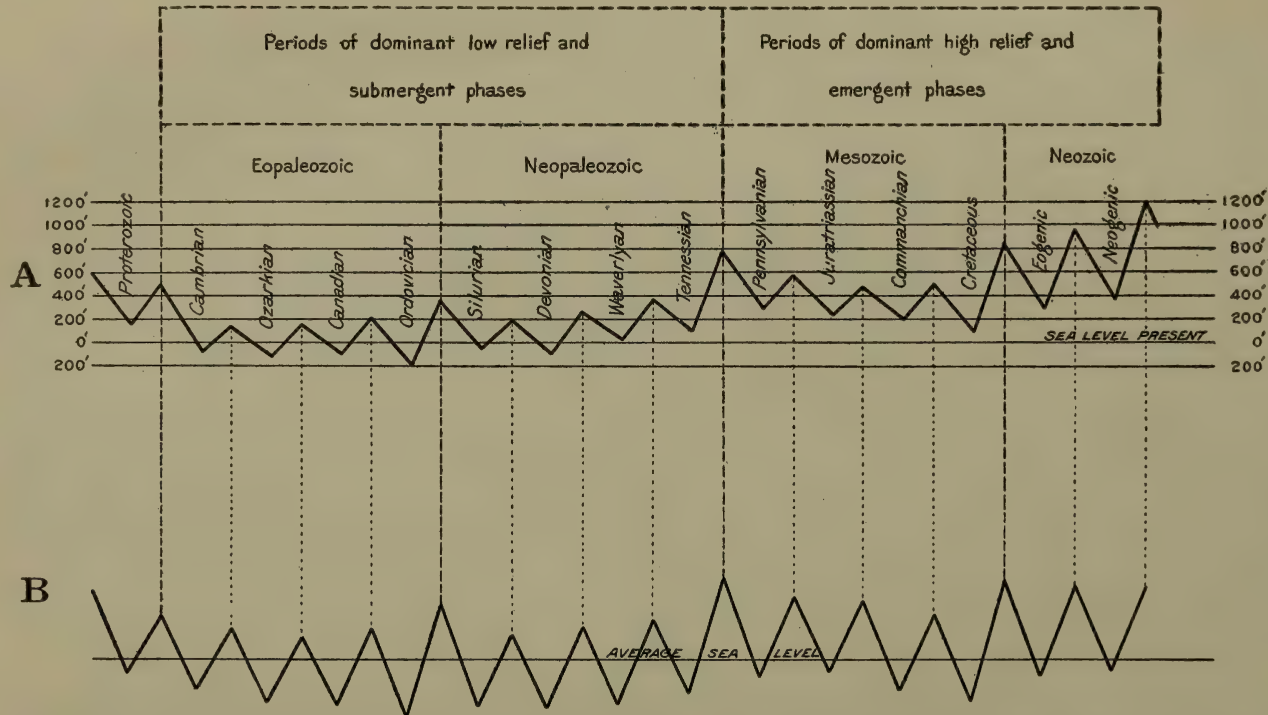

FIGURE 4.—*Diagram illustrating (A) Fluctuation and Oscillation of average Relief of median Areas of North America with respect to Sealevel, and (B) relative vertical Displacement of the Strandline in successive Periods with respect to an assumed average Sealevel.*

In A the average relief at the present time is assumed to be about 1,000 feet. For the whole continent the average relief, as estimated by good authorities, is nearly 2,000 feet. The oscillations in B are not drawn to a definite scale in feet. However, it seems probable that the total average displacement in any one period did not exceed 1,000 feet. Locally it may have been much greater. (For Neozoic read **Cenozoic.**)

During the periods of the Eopaleozoic and Neopaleozoic eras, the sedimentary record of which in the continental basins is mostly accessible, submergent conditions predominated. In the Mesozoic and Cenozoic ages, however, the marine sedimentary record of which is supposed to be largely inaccessible, land or emergent conditions were dominant. It is to be observed that in both diagrams—A showing average relief and B the maximum vertical displacement—the curve is accentuated between the Ordovician and Silurian, the Tennessean and Pennsylvanian, and the Cretaceous and Eogenic, which respectively include the three periods of maximum diastrophic activity. That the average relief of the continents at these times was actually greater than in respectively preceding and succeeding periods is shown conclusively by the extraordinary amounts of clastic sediments laid down in these ages. The same criteria, particularly when the distribution of the clastic deposits is considered, indicate also greater diversity of relief, a condition that is suggested again by the fact that the unconformities at these boundaries are more clearly marked than usual. (See "Gradational and Lithological Criteria," page 467.)

Marine invasions from the four sides of the North American continent.—The principal oscillations of the strandline in North America during the Paleozoic are shown graphically by the diagrams occupying pages 346 and 347. These indicate the direction and extent of a large number of invasions of the continent by, respectively, Gulf of Mexico, Boreal (chiefly by way of Hudson Bay), Pacific and Atlantic waters and faunas. The east-west extent of the Pacific and Atlantic invasions is indicated according to the location of easily understood longitudinal topographic and geographic areas crossed by the respective waters. The north-south extent of the Gulf and Boreal invasions is determined by degrees of latitude, the area plotted being included between the 30th and 75th parallels. When communication between the waters of two or more of the oceans occurred, or when faunas that are provincially distinct but so nearly of an age that they fall within a single time unit of the rank discriminated on the charts, the approximate location of the resulting real or apparent intermingling of faunas is indicated by the letters G = Gulf of Mexico, P = Pacific, A = Atlantic, and B = Arctic or more accurately Hudson Bay.[17] The letter C indicates expansion of Pacific waters northward or southward in the Cordilleran Basin.

[17] As stated on pp. 365 and 370, intermingling of faunas of distinct oceanic basins occurred much less often than is suggested by our most detailed paleogeographic maps. These maps are yet too synthetic to represent the facts of faunal distribution accurately. Usually the indicated communication means no more than that the fauna of, say, the Arctic type, invaded areas more commonly occupied by Gulf, Atlantic, or Pacific faunas, and especially that such opposite and as yet undiscriminated invasions took place within the time embraced in some paleogeographic map.

Intersystemic intervals.—It will be observed that the withdrawal of the seas is represented as complete at the close of each of the successive periods. By complete withdrawal is meant a condition like the present—that is, a retreat of the waters to the marginal shelf on which the record is buried beyond present possibilities of investigation. The supposed duration of these intervals of complete withdrawal is indicated by the relative width of the unshaded spaces at the margins of the diagrams. The break between the systems is great where the space is wide on all of the four invading sides, and where it is narrow on any side the interval of non-accessible record is thought to be relatively short. It seems to have been shortest between the Silurian and Devonian and not much longer between the Ordovician and Silurian and the Devonian and Waverlyan. It is thought to have been longer between all the others. As organic evidence favoring this hypothesis I would point out the fact of close relationship exhibited by the faunas of, respectively, the late Ordovician and early (Richmond) Silurian, the late Silurian and early Devonian, and late Devonion and early Waverlyan. These were the periods of greatest submergences. They are also the systems that, despite their great wealth of fossils, have given the greatest trouble to bound, so long as faunal evidence alone was considered. The relatively gradual passage of the older to the newer of these faunas should be contrasted with the sharper life breaks separating all the other Paleozoic systems.

When the intersystemic interval is short a large part of its record has sometimes been made in greatly reduced continental sea basins and in land deposits in areas adjacent to relatively permanent "positive" regions. Examples would be the late Cincinnatian marine deposits in the southwestern part of the Ohioan province and contemporary land deposits (Oswego and Juniata sandstones) in Pennsylvania and New York; marine Cayugan sediments in the middle Appalachian Valley region and mostly lake or land deposits farther inland; late Devonian of marine origin in various parts of the country and land deposits of corresponding age in New York and Pennsylvania. When the interval is long the marine record is wholly confined to inaccessible marginal areas and the local land deposits that may have been made in the earlier part of the interval were in part or whole removed again in the course of base-leveling before the succeeding submergence of the next period could cover and preserve them. The Pleistocene land record, for instance, is relatively new. Under a drier climate it might all be removed before another marine submergence solidifies and preserves it. At best only remnants could be preserved.

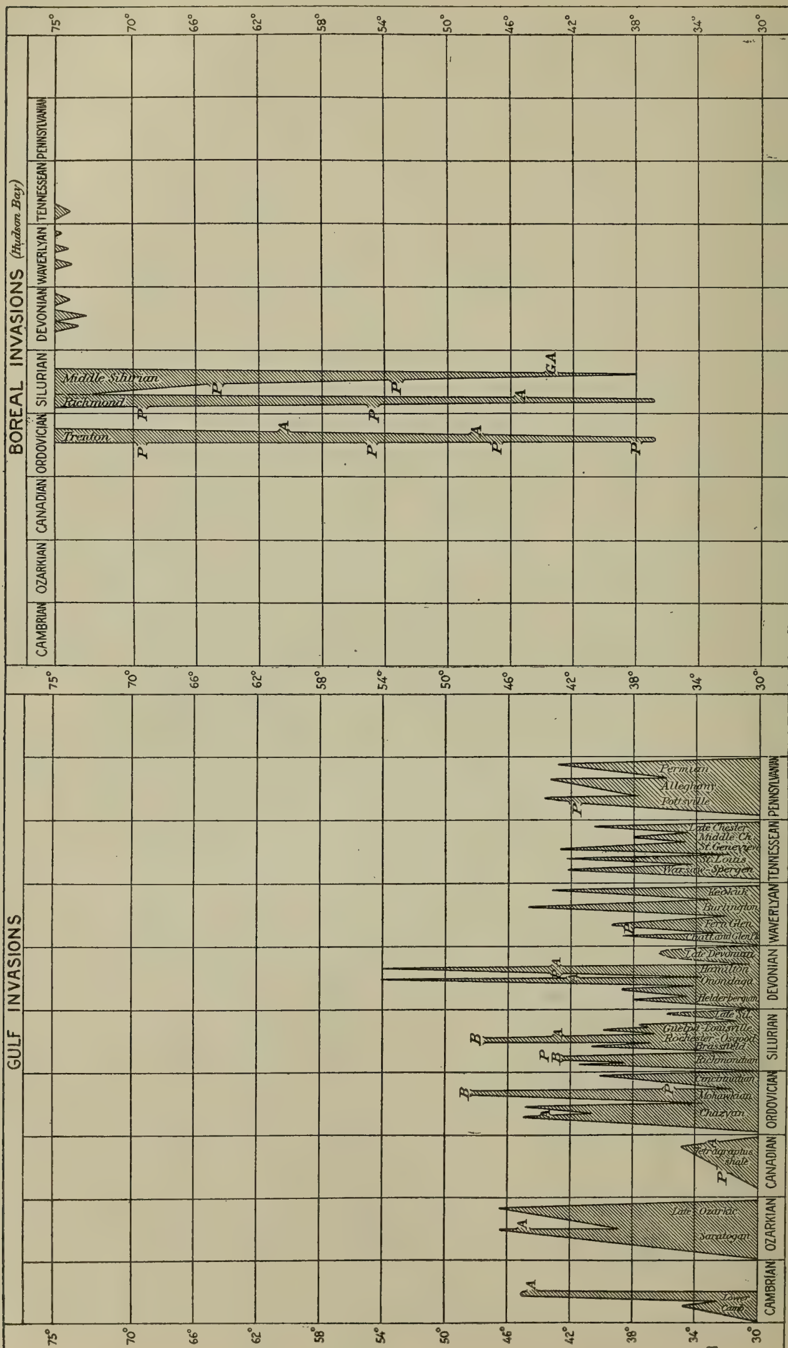

FIGURE 5.—*Diagrams illustrating Gulf and Boreal Invasions*

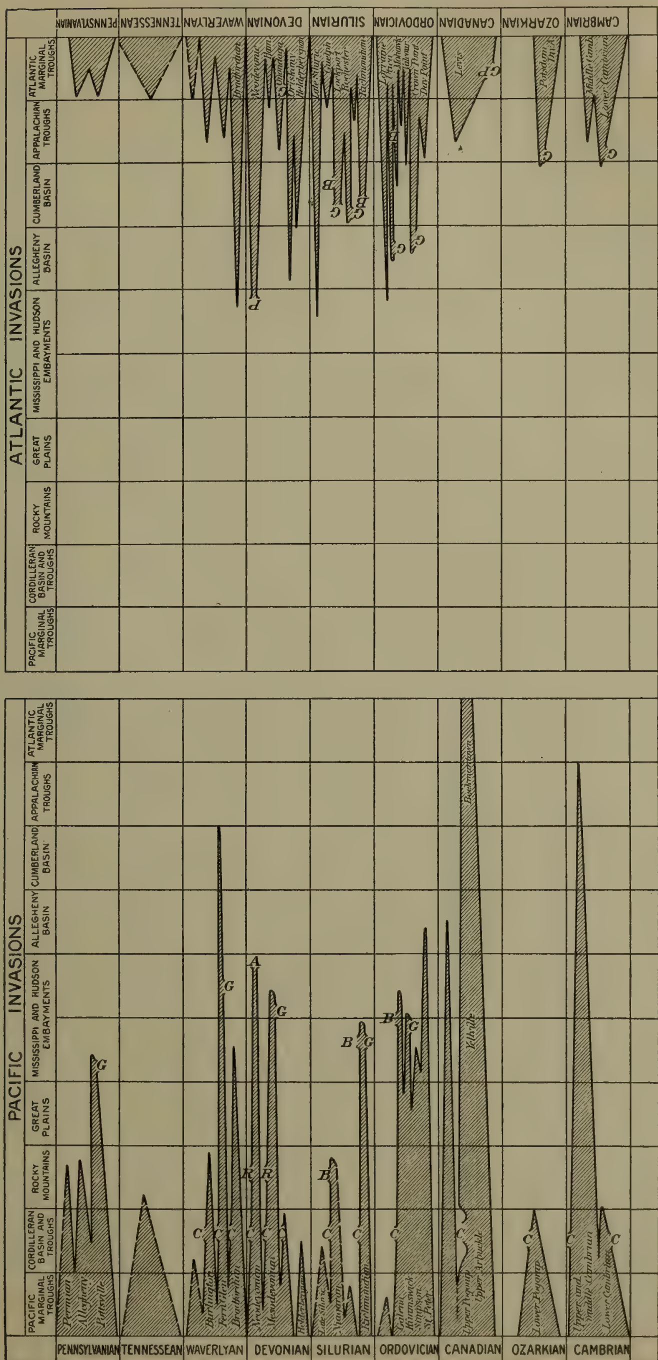

FIGURE 6.—*Diagrams illustrating Pacific and Atlantic Invasions*

As stated, the relative lengths of the intersystemic intervals seem to be indicated by the presence or absence of local land deposits in interior areas and by other phenomena. For instance, when the median depression of the continent—that is, the area connecting the Mississippi and Hudson embayments—was submerged by invasion from either direction, as in the Ordovician, Silurian, and Devonian periods, then the ensuing retreat of the seas passed through fluctuating stages that are largely recorded by well known land and marine deposits on the continent itself. When, on the other hand, the submergence failed to embrace a large part of this median depression, then the retreat cleared the continent so rapidly that the intersystemic stages could leave no accessible marine record, and the emergence endured so long that all the possible land deposits were removed from interior areas. The difference between the two conditions and the idea which it is intended to convey may be better appreciated when it is understood that all evidence bearing on the point leads to the inference that while the submergences were as a rule gradual, the retreat of the waters was more impulsive and relatively rapid.

Comparison with Schuchert's submergence and emergence curves.—The diagram illustrating the successive invasions and retreats of oceanic waters obviously also represents submergences and emergences of the continent. Decided differences appear when they are compared with the curves prepared by Schuchert from his paleogeographic maps.[18] These curves, while doubtless correctly presenting the relative proportion of continental marine waters shown on his maps, are yet, I maintain, a quite inadequate presentation of the actual movements of the strandline. The low points representing submergences are in most cases probably as near the truth as we can get just now, but the high points, showing extremes of emergence between the periods, go no farther than the lowest stage of the strandline that according to his information he regarded himself justified in mapping. Now, considering that, in every "Paleozoic" case, at least, the contact between the top of the preceding and the base of the succeeding system indicates an hiatus in even the completest sections so far observed, Schuchert's curves obviously fail to do sufficient justice to the emergences. In short his curves are inadequate to the extent that they fail to account for the stratigraphic hiatuses, which in fact constitute the most important of all the diastrophic criteria relied on in distinguishing the successive systems, series, and groups. The gravity of the failure is particularly evident in the case of the boundary between the Tennessean and Pennsylvanian, between the Waverlyan and the Tennes-

[18] Bull. Geological Society of America, vol. 20, 1910, pl. 101.

sean, and between the Chemung at the top of the Devonian and the next overlying Waverlyan ("Mississippic") system which I begin with the Chattanooga shale in Alabama, middle Tennessee, and Arkansas, and with the Cleveland shale in Ohio. In all of these instances, indeed between all the systems and many of the divisions of less rank, the evidence of complete withdrawal of seas from at least the eastern part of the continent seems indisputable.

Time values of systems.—In estimating relative time values of systems it is essential to consider the probable duration of the non-accessible deposition intervals as well as the parts represented by marine sediments in continental seas now exposed to view. This introduces an element of great uncertainty into estimates purporting to give the probable duration in years of periods and eras, and positively negatives all attempts that fail to take these intervals into account. That the principle is generally recognized in practice so far as continental marine deposits are concerned is shown by the fact that the time values of formations and groups of formations are determined by the fullest available sedimentary record and not by records which by comparison we know to be much less complete, or indeed but fragmentary. Including these intervals of non-accessible deposition the total of geologic time is greatly augmented. The time value also is increased proportionally for those periods which are less fully represented by deposits in continental seas than are other periods during which the average elevation of the continent above sealevel was less and in which, consequently, the available depositional record is less defective. Without taking this factor into consideration, and believing that the respective time values of the successive periods are not greatly unequal, the known deposits of the proposed Waverlyan and Tennessean systems or periods, for instance, would scarcely be sufficient to justify their separation. Large parts of these periods, namely, are thought to be included in long intervals of inaccessible record that preceded in the one case the Warsaw, in the other the Pottsville submergence. Both of these cases are preliminary stages of the emergent phase of the North American continent that culminated in the Permo-Triassic interval. Following the Triassic the balance of continental oscillation again favored submergence. this particular cycle attaining its maximum marine invasion in the Cretaceous.

Except to say that I believe the age of the earth, beginning with the Cambrian, is much greater than 70,000,000 years, the amount that since Walcott's estimate in 1894[19] is being rather generally accepted as satis-

[19] Proc. Am. Assoc. Adv. Sci., vol. 42, 1894, pp. 129-169.

factory, I have no opinion to offer regarding the value in years of the respective periods and eras. The criteria on which all such estimates have been based are insufficiently understood and moreover seem too variable to afford trustworthy data. All I am certain of is that geologic time is very long and ample for the slow evolution of the earth and of the life on it.

Relatively hopeless imperfections of the sedimentary record.—The more important of the breaks in the stratigraphic record, of importance chiefly because they include the hiatuses most likely to remain unbridged, are the intervals of very great general emergence. I refer especially to the intersystemic intervals when the continents were large and the seas confined to the oceanic basins. Some of these emergent intervals were very long, and considering geological time as a whole their average duration seems to have increased with time, as did also the average elevation of the continents above sealevel. Their duration, further, seems to be in proportion to the greatness of the emergence, the longest intervals being those in which the continents were largest. Following the idea expressed on page 342, the intrasystemic breaks in the median parts of the continent also were greater than usual in the periods next following and preceding a long intersystemic interval. The continental seas during such periods were on the whole more limited in extent than in periods separated by shorter intervals. Long, intrasystemic intervals of inaccessible marine sedimentary record are suggested for the Canadian, Waverlyan, Tennessean, Pennsylvanian, Jura-Triassic, and Comanchean, whose continental seas were relatively restricted, while shorter intrasystemic intervals are indicated for the Ordovician, Silurian, Devonian, and Cretaceous periods in which the continent, particularly its central and northern interior parts, was widely submerged.

The marine record of these great intersystemic and intrasystemic intervals of emergence, being wholly or at least mainly confined to the oceanic basins and the marginal shelf of the continents, is now quite inaccessible. They are, I fear, really "lost intervals." All we can hope to learn concerning the history of these intervals is the unsatisfactory information to be gathered from a study of the phenomena directly connected with the breaks in the stratified column and from the more definite though yet very incomplete organic and physical data preserved in the land deposits.

Doubtless land deposits were made in all of these emergent intervals, but it is no less clear that the longer they endured the more complete the removal of such deposits by the ever-active agencies of baseleveling. Hence, absence of such deposits when extensive lands are indicated by

other criteria argues for long durance of such conditions; and the longer baseleveling operations were in play the greater the lack of positive information concerning the ill-recorded interval. In this connection it is significant to note that, with the doubtful exception of the Saint Peter and Sylvania sandstones, the sand of which was cemented by lime infiltration as it was covered by the advancing sea, and possibly certain Pennsylvanian sediments, there are no strictly land deposits of pre-Pleistocene age in the median (Mississippi Valley-Hudson Bay) depression of the North American continent. In this great flat area land deposits could never have been very thick, but what there was baseleveling agencies removed before the several accumulations could be consolidated and preserved beneath succeeding marine deposits. They passed away just as the Pleistocene deposits are being removed from the same area today.

Preservation of land deposits was favored only in areas of considerable downwarp, and in these only while the area was subject to merely broad folding and not to close folding or high elevation with consequent erosion prior to subsequent submergence. It is primarily to this circumstance that we owe the preservation of the late Ordovician-early Silurian and the Devonian land deposits in the middle Appalachian and Allegheny regions; also of the Jura-Triassic deposits in the broad depressions of Appalachia and Taconia, which latter areas had passed the stage of close folding and after the Jurassic moved inland bodily. (See page 435.) The Mesozoic and Tertiary land deposits of the Rocky Mountains area were similarly preserved because they lie mostly in broad depressions unfavorable to extensive or complete removal. The much greater inland extent of the western areas of development and preservation of land deposits than in the eastern part of the continent is connected with the principle of "suboceanic spread." On account of the much greater width and the somewhat greater depth of the Pacific than the Atlantic the forces developed beneath the former produced folding much farther inland than did those originating beneath the Atlantic.

Though we may gain an obscure idea of the conditions prevailing during some of the Paleozoic emergent stages, of the most of them we know and probably can learn little or nothing of a definite nature. Concerning the pre-Cambrian or earliest Cambrian the discovery of facetted pebbles by Willis in China makes it probable that glaciation prevailed locally at that time. Then we are justified in inferring considerable local elevation (chiefly in the marginal lands), active erosion and vulcanism as beginning in the closing stages of the Ordovician and continuing into the early Silurian. Elevation and consequent erosion is indicated also toward the

close of the Devonian and again early in the Pennsylvanian. But of land faunas and floras during the first and second of these four stages we know absolutely nothing. Regarding even the third and fourth stages our knowledge respecting their land faunas is very imperfect. As to the long intervals that elapsed between the accessible records of the other Paleozoic systems little indeed is known of the physical conditions that prevailed on the lands of these times and nothing whatever of the probable organisms. Much may have happened in these obscure intervals. Whatever we may say concerning them, and however plausible, it may be no better than pure speculation. I shall venture only a few suggestions concerning climatic changes.

CLIMATIC VARIATIONS

Frequent alternations of warm and relatively cool climates.—Taking the geological marine record, as preserved in the fossiliferous rocks from the Cambrian to the Tertiary, it suggests equable, mild, almost subtropical climates over the whole northern hemisphere in all the ages represented. Yet there is strong reason to believe—may we not say we know?—that frigid conditions occurred at least locally at the beginning of the Cambrian and again early in the Pennsylvanian.[20] Admitting that there were icy ages, and considering the 5 or 6 advances and retreats of the ice-sheet now recognized in the Pleistocene, is it unreasonable to suggest that many other periods of relatively low temperature occurred during the ill-recorded emergent stages of the Paleozoic, Mesozoic, and Cenozoic, of which we have as yet no positive information?

The accessible marine record in the northern lands usually represents only the more extreme submergent stages of the periods, therefore of ages in which the lands were low. Besides, the character of the Paleozoic deposits in the higher latitudes indicates moderately moist, equable and warm climates, and certainly not arid conditions. Aridity would have favored torrential deposition of clastics which we know are almost insignificant in amount there. But what about the intervening ages that have left no accessible marine record in these northern areas?

It seems to me, that given sufficient moisture, relatively cool climates with ice formation occurred wherever and whenever large and high land

[20] The assumption of locally frigid conditions in the early Pennsylvanian is based primarily on the fact that erratics of all sizes, some as much as 20 feet across and 5 or 6 feet thick, occur in the Caney shale of eastern Oklahoma. These were transported not less than 50 miles and many probably were carried much farther. No other competent means of their transportation than ice—presumably heavy shore ice—has been suggested.

prevailed, and warmer climates always returned when the continents had been reduced by erosion or other processes to approximate baselevel, and when they were more or less widely submerged beneath the oceanic waters. Under this supposition relatively frigid conditions may have occurred during any of the highly emergent phases. But the subject is exceedingly complex and many other factors, such as the depletion of the moisture and carbon dioxide content of the atmosphere, clouds and change in prevailing direction of winds, and the absorption and radiation of heat under varying climatic conditions, some or all of which doubtless contributed and possibly were more important in bringing about climatic changes than were elevation and size of land areas. Regarding most of these other causes all I care to say at present is that their operation probably was very effective only at times of exceptional continental expansion and elevation.

Another suggestion relating especially to the several advances and retreats of the Pleistocene ice-sheets: Assuming that elevation is competent to bring about glacial conditions in areas of abundant precipitation, it seems to me that the subsequent melting and retreat of the ice-cap may be due chiefly to subsidence of the areas, and that the subsidence resulted from overloading. In other words, that the isotatic equilibrium had been disturbed by loading, and that subsidence set in when the ice attained a certain limit of thickness. As the loaded areas sank, more widely distributed compensatory upward movement probably occurred in the more interior unglaciated regions. Reaching the level of melting, the ice-cap was gradually removed, only to be rebuilt when the direction of movement was first stopped and then reversed. By such alternate loading and unloading we may perhaps explain the unquestionably established periodic advance and retreat of the ice-sheet. That the process here briefly outlined, which is in essential accord with the views of Dutton, de Geer, and others, is of itself competent to cause the alternations of growth and restriction of the ice-sheet I am not prepared to say, but that the effect of overloading comparatively local areas with ice, in the way of unsettling isostatic conditions, has not received adequate consideration from most of those who have sought to account for the observed phenomena, seems undeniable. Perhaps, because of my high regard for the principles of isostacy, I am overestimating their bearing on this Pleistocene problem. However, since these physical problems are somewhat out of my special lines, it is with much diffidence that I venture an opinion.

The hypothesis of reversed oceanic circulation.—In passing it seems desirable to notice an important suggestion made a few years ago by

Chamberlin[21] and more recently advocated by Willis,[22] namely, that the present deep-seated circulation of the ocean toward the equator is abnormal, and that the more normal condition is a northward movement of warm, highly saline waters in the depths instead of at the surface. The special purpose of the hypothesis is to explain the extraordinarily mild climates that prevailed in many geological ages in the Arctic regions. I question, however, if it is competent to do so. I do not wish to say that such a reversal of oceanic circulation did not occur, for indeed the arguments on which the idea is based seem reasonable. I admit further that it might be accepted as a satisfactory explanation of the presence of subtropical plants in Greenland in the Tertiary; also that reversal may have occurred toward the close of a highly emergent stage, or in the early part of the succeeding submergent phase, of neither of which the marine record is accessible; but that it explains the occurrence of the same marine faunas in the polar regions that are found in temperate and tropical zones in most of the geological periods from the Canadian on to the Miocene I can not admit.

In the first place these faunas, with very few exceptions, are all littoral or near-shore faunas, and their migrations, whether in the oceanic or the continental basins, are almost confined to the shore and bottom of the shallow seas in which they thrived. With organisms so sensitive as these to changes in temperature and depth, extensive migration under any but equable climatic and bathymetric conditions would have been highly improbable if not impossible. As corals and other animals that are now restricted to warm waters did so migrate, we must assume either that at such times mild climates prevailed or that in ages preceding the present these organisms were not affected by changes in temperature—a conclusion altogether repugnant to the zoologist. Assuming that they were then as now sensitive to temperature changes, their fossil occurrence in all latitudes must be accepted as proving at least occasional times of universally mild climates—that is, such conditions prevailed in at least the relatively brief geologic ages of which we have a marine sedimentary record in the boreal continental basins. What occurred in the long intervening ages of which no satisfactory life record is preserved in the far northern continental basins we may only surmise, or possibly infer from evidence found elsewhere.

Warm climates being thus established for the shallow northern continental basins during their occupancy by marine waters, similar condi-

[21] T. C. Chamberlin: Journal of Geology, vol. 14, 1906, p. 363.
[22] Bailey Willis: Science, N. S., vol. 31, No. 790, 1910, p. 245.

tions are even more certainly proved for the larger and deeper oceanic basins. Obviously, the temperature of the epicontinental waters is more readily susceptible to modification in accord with climatic conditions prevailing in adjacent continental regions than is that of the great oceans. A fall in average atmospheric temperature that would soon render the continental seas unfit for warm water marine life would have much less effect on a similar fauna of the deeper oceanic basins.

Now, according to the theory of reversed circulation, warm waters sank in the equatorial zone and reappeared at the surface in the polar regions. Could they have carried the littoral warm water faunas with them? Manifestly, no. Or, could these faunas have migrated in their usual manner along the shore? Again we must say no, since the hypothesis requires a southward movement of cool superficial waters, which would have effectually barred shore migration. Then how did the warm water faunas get to the Arctic regions?

If we did not know that essentially the same pre-Miocene fossil faunas are found as far north along the Atlantic and Pacific as the deposits have been traced, it might be suggested that the passage to the Arctic was effected during the transition to the "abnormal" condition of northward superficial circulation, and that at other times the similarity of the periodically separated faunas was maintained by "autochthonus," or perhaps better by "geminate" development. However, in the face of this and other facts of faunal distribution the argument seems indefensibly weak. It becomes questionable then if reversal of oceanic circulation was ever an important factor in faunal distribution. Indeed, we might go further and doubt that actual reversals ever occurred.

Another hypothesis having an important bearing on the problem, so far at least as the Atlantic is concerned, is the land connection between North America and Europe which is believed to have existed at various times in the Paleozoic. Clearly, if such a connection is admitted, deep-seated circulation between polar and equatorial basins through the north Atlantic would have been impossible. Nor could it have occurred through the continental seas, since these were but seldom if ever great inter-oceanic thoroughfares, and they were never deep enough to suggest deep-seated circulation. After all is said, it appears that the fossil faunas migrated north and south along the shores when climatic and other physical conditions were favorable, which seems to have been whenever the continents were low and small; and that such migrations were prohibited in the occasional highly emergent phases. Whether reversal of oceanic circulation occurred in the latter periods there seems no conclusive means of determining, but that such reversal was in no wise responsible for the

northward migration of southern Atlantic faunas appears reasonably assured.

Significance of black shale deposition—Distribution and characteristics of the shale.—Typical, non-calcareous black shale deposits are found apparently in the marine formations of all continents. They are not confined to any particular era, but seem to have been laid down in one area or another in most, if not all, of the geological periods. Partially reviewing only the North American Paleozoic occurrences, we may begin with the Lower Cambrian black slates in Vermont (the Georgia), in the Appalachian Valley, and in the Cordilleran trough in western Nevada. Then there are good deposits of Canadian age in the Saint Lawrence Valley, in Vermont and eastern New York, in west central Arkansas and in the far west, and the same regions contain other thick beds ranging from early to late Ordovician in age. Silurian shales of this kind are found in the Ouachita area of Arkansas and in Alaska. The Utica is the first and the Maquoketa the second to transgress far inland beyond the submarginal troughs to which the earlier black shales are almost confined. The Devonian includes some of the best known examples, notably the Genesee. The Chattanooga, which is early Waverlyan in age, spreads more widely in the interior basins than any other, being recognizable and of extraordinary thickness in Oklahoma on the southwest and along Lake Erie, where it is represented by the Cleveland and probably the Sunbury, in the north. The Tennessean, so far as known, contains black shales only in northern Arkansas. The Pennsylvanian, however, includes many relatively thin beds besides a few that, like the Caney in Oklahoma and its extensions to the south in Texas ("Bend shale") and to the north in Arkansas and Missouri ("coal-bearing shale" of the Morrow), are thick and widely recognizable.

Many of these black shales attain great thicknesses, especially in the submarginal troughs, where apparently uninterrupted measures of 1,000 feet or more are not uncommon. A notable feature is the great areal extent of these formations, even when but 50 feet or less in thickness. Before beginning the discussion it should be said that calcareous black shales, like the Marcellus and Hamilton formations, are not included.

Objections to prevailing interpretations.—Black shale deposition has been variously interpreted. Some of the more notable instances have been rather generally thought to indicate Sargasso-like conditions in a broad open sea. Other writers, on the contrary, have recently come to the conclusion that they represent deposits in an "inclosed marine body . . . of great depth and imperfect vertical circulation" (Clarke[23]), or that they

"denote closed or stagnant arms of the sea . . . as in the Black Sea of Russia" (Schuchert[24]). I am inclined to question, more especially the later quoted interpretations, on the grounds (1) that these deposits are usually very widely distributed, (2) that black shale faunas comprise little else than floating marine organisms often strictly cosmopolitan in habitat and therefore requiring currents to effect their distribution, and (3) that the beds overlap to extinction on the flanks of certain interior areas of uplift without material changes in character.

The facts at the basis of the last objection are furnished by the Chattanooga shale, which pinches out on the very gently sloping surface of the Nashville island of the time and likewise dies out on the southwestern side of Ozarkia. Similar conditions were observed concerning other no less typical examples of black shale, like the Utica, or the much younger black shale of the Morrow group in Arkansas, Oklahoma, and Missouri. The physical phenomena associated with these overlapping shales establish beyond question that, however extensive, the pans in which the shales were laid down were always very shallow, and this fact proves that great depth of water is not a requisite in black shale deposition. The common though local occurrence of thin seams of coal in the Chattanooga, not to mention the greater development of coal in the Pennsylvanian black shales, tends to the same conclusion.

As to the facts relied on for the first and second objections, they seem to show conclusively that the Paleozoic black shale deposits in America do not indicate either "stagnant" or more than usually "inclosed" bodies of water that might with any show of right be compared with the Black Sea of today. Not one of these black shale depositing seas can be shown to have been more inclosed than the majority of limestone depositing seas which occupied essentially the same areas in preceding and intermediate ages. And why they should be characterized in general as denoting "stagnant arms of the sea" is not at all clear in the majority of cases. That the Utica was frequently in, and perhaps always maintained, ample communication with the Atlantic is shown by the distribution of its current borne pelagic species as far west as central Kentucky, beyond which the sea did not extend. Much the same may be said of the Devonian black shales in the middle Appalachian Valley and western New York, the waters and life of which must have invaded from the east and not as Clarke believes from the west. Nor are the facts materially different in the case of the Chattanooga except that these waters evidently invaded

[23] J. M. Clarke: N. Y. State Museum Rept., 57, vol. 3, memoir 6, 1903, p. 200.
[24] Charles Schuchert: Bull. Geological Society of America, vol. 20, 1910, p. 446.

from the Gulf of Mexico and spread in shallow continental basins to central Oklahoma on the west and northern Ohio in the opposite direction, or in the case of the similarly distributed Pottsvillian black shales, which are widely distributed in the Mississippi Valley.

Black shale faunas.—In all cases of typical black shales the faunas are strikingly uniform. Littoral and benthonic faunas, of the usual warm water facies, are practically absent. Of brachiopods we see only the phosphatic inarticulate shells, such as *Lingula* and *Discina,* ubiquitous and evidently hardy types that seem to be less susceptible to changes in temperature and character of bottom and water than most other marine organisms. The mollusca are all thin-shelled, and as a rule depauperate, and among them the pelecypods are mostly byssiferous forms that are as likely to attach themselves to floating as to fixed objects. In short the general aspect and composition of black, non-calcareous shale faunas is very different from that of the limestones and calcareous shales, whether blue, green, or black, that are found in the same areas. The latter faunas comprise chiefly species dependent on mild temperatures, shallow depths, and favorable bottom conditions and shorelines for their existence and migration; the former, on the contrary, include few or no species so limited.

The graptolitiferous black shales of the Levis, Athens, and Ouachita troughs, in which there are thicker beds of such shale than anywhere else in America, prove as certainly as anything may be established by faunal evidence that inclosed and stagnant conditions are not essential in black shale deposition. That most graptolites were pelagic in habitat and passed from one ocean basin into another solely by means of marine currents is universally accepted. They could not have entered a continental basin except a marine current carried them in, and there is no normal possibility of their transportation to the head of a narrow bay. Consequently, when it is established that the deposits in question are confined to narrow strips hundreds of miles in length, it is at the same time proved that they were laid down in channels open at both ends so as to give free passage and egress to the graptolite bearing currents. Marine thoroughfares like these surely can not be called inclosed, nor does it seem possible that they could have become stagnant. And the not infrequent occurrence of intraformational conglomerates in these graptolite shales is almost conclusive proof that the channels were not of unusual depth.

Obviously, black shale deposition took place under varying conditions of depth and degrees of inclosure. We find similar black muds forming today in the stagnant depths of an isolated Black Sea, and in Paleozoic

ages they were deposited in shallow or perhaps comparatively deep channels with evidently perfect circulation as well as in broad shallow pans in which, except at times when they were abundantly peopled by certain kinds of marine animals, circulation may have been very sluggish and imperfect. The vertical distribution of the marine organisms in the last suggests that the wide seas which filled the shallow interior basins with black shale may well have been stagnant during most of the time in which such deposits were being laid down. Marine faunas are never found generally distributed through the mass of these black shales. They occur only in occasional thin seams, in which, however, their remains are likely to be very numerous, and the best of these—indeed it may be the only zone with such fossils in hundreds of feet of shale—is usually in the basal foot or two. Although there is no appreciable macroscopic difference between the shale without marine fossils and the matrix of the thin bands crowded with them, it yet seems probable that the extinction of marine life is in many cases due to increased fouling of the water by decaying vegetable matter. Marine life could have existed in these waters only as long as the upper layers remained uncontaminated.

Vegetable fouling of at least the post-Silurian instances of inland black shale seas—whether acquatic or terrestrial, or both, in origin is not of immediate importance—almost certainly prevailed. Similar fouling in the earlier cases is less probable but not impossible. That it did occur as a rule is assumed without argument except to say that something of the kind is required in accounting for the high percentage of carbonaceous matter in these shales. This condition also explains the common absence of marine shells better than does the suggested dissolution of the calcareous shells in the deep, acidulated waters. But it does not account for the absence of littoral faunas along the shores, since here the waters were subjected to sufficient agitation to keep them fit for the existence of such life. The fine conglomerates and beach sands which occur at the base of the overlapping Chattanooga shale in central Tennessee and in northern Arkansas clearly prove the presence, at least locally, of a littoral zone that should have been admirably adapted to near shore faunas. But excepting the hard jaws of errant annelids and an occasional fish bone, there is no sign of contemporaneous strictly benthonic life.

Cool climates a possible cause.—Depending on such evidence, I have been led to the conviction that great depths and inclosed conditions are seldom if ever essential factors in the origin of black shales. In casting about for a more generally applicable explanation the thought

suggested itself that their origin is in some manner connected with cool temperatures. It is not that glacial climates prevailed at such time, but only that the average, or at least occasional, temperature on the lands adjacent to the continental seas was too low to encourage the development of normal littoral faunas. In other words that the climates prevailing at times and places of black shale deposition in continental seas were cool enough to render their shores inhospitable to contemporaneous littoral and benthonic life. Decidedly frigid conditions may have obtained occasionally or locally during such times but they are not essential to the proposition.

Various other facts might be cited in support of the suggested relation of black shale deposition to cool climate. Thus black shales occur in greatest abundance in submarginal regions. All agree that these were frequently elevated to considerable altitudes, a condition doubtless tending to lower the average temperature of adjacent land seas. In the more interior areas black shales were formed chiefly toward, or soon after, the close of periods (the Utica, the Genesee, the Chattanooga, and the Fayetteville), or near the close of epochs (the Caney-Morrow), hence when local highly emergent conditions, presumably favoring diversity of climates, commonly prevailed. Migration of littoral and benthonic faunas from the oceanic basins (on which cold temperatures prevailing on adjacent lands would have had comparatively little effect) into the continental troughs and basins must under such conditions have been very limited and perhaps were soon stopped entirely. Only the current borne pelagic forms, which are much less affected by unfavorable shore conditions, could have entered and existed in the interior basins. The very slight amount of calcareous matter in black shales also is suggestive of cool rather than warm climates. This is inferred from the fact that all classes of marine invertebrates, especially reef corals and associated bryozoa, on which warm waters are confidently postulated by paleontologists, are wholly absent in black shales and almost confined to calcareous deposits.

The Pennsylvanian black shales, considering that until recently this period has been universally regarded as favored by an unusual extension of warm climates, may suggest an exception. But I am not at all convinced that this period was especially warm. The prevalence of clastic sedimentation indicates contributing lands of considerable altitude, which should have tempered the climate. Peat deposits are being formed today mainly in northern regions; and 30 to 40 feet of coal are included in the Permo-Carboniferous glacial deposits in Australia. Further, the Caney

black shale in eastern Oklahoma contains great, evidently ice-transported boulders, and glaciated boulders are found in similar shales in Australia. The Pottsville conglomerates, too, are highly suggestive of glacial drift. Finally, as to the evidence furnished by the Pennsylvanian floras, this seems to favor the newer interpretation quite as much as the old. Taking the case as it stands it must be admitted that the Pennsylvanian black shales, like those of earlier ages, are more readily explained on the assumption of cool climates and shallow, perhaps swamplike, seas than under the hypothesis of deposition at great depths in inclosed basins.

Regarding the suggested relation of black shale deposition to cool climates it must be admitted that as a general explanation the proposition is not altogether satisfactory. Probably the real cause, if there is any that operated alike in all cases, remains to be discovered. So far we have established only that none of the black shale deposits in America is comparable in the matter of depth and inclosure of waters in which they were laid down to the black muds in the Black Sea of today. Also that there is no warrant for the unqualified assertion that black shales denote stagnant arms of the sea.

SHALLOWNESS OF PALEOZOIC CONTINENTAL SEAS AND ABSENCE OF STRONG, TRANSCONTINENTAL CURRENTS

Continental seas generally very shallow.—The few selected facts which have been discussed on preceding pages, and to which is to be added much similar evidence incidentally brought out later on, will probably suffice to establish the average exceedingly low relief of Paleozoic lands. It is reasonable to infer that the continental seas were correspondingly shallow. Direct evidence on depth of waters is afforded by the Richmondian and Niagaran embayments of the Nashville and Ozark uplifts. Granting, further, what I believe all will admit, that the present depth of simple downwarps is probably greater, and can not be less, than it was at the time of their occupancy by arms of Paleozoic seas, the facts observed in something like 20 instances of such embayments indicate beyond question that the maximum depth of their waters at no time exceeded 100 feet and generally must have been much less. As regards depth of the broader interior seas direct evidence concerning the older Paleozoic is almost wanting. Subsequent and repeated accentuations of the originally doubtless very gentle warps have deeply buried the competent factors. Judging from the present altitude and slow rate of overlap of the Kinderhook, Chester, and lower Pottsville deposits, which lie on the south flank of the Ozark dome and certainly failed to extend over

it, the evidence is altogether indicative of very shallow seas. Other evidence leading to the same inference is found in the frequent lateral and vertical oscillations of the continental seas, again in the presence within the area of the Appalachian Valley of narrow lands positively shown by physical criteria to have been, as a rule, of low relief, and finally in the wide distribution of bottom-dwelling species and faunas, whose dispersion across great depths would have been practically impossible. Deep wells have repeatedly proved the existence of the same faunas, apparently no less well developed and abundant, hundreds of miles out from the known shores of the sea in which they lived. A very convincing instance was recently afforded by a middle Eden fauna of thirty species taken about 2,000 feet beneath the surface at Waverly, Ohio.

Depending on such evidence, I have come to entertain the belief that the average depths of the Paleozoic continental seas were less than 200 feet, and that none attained depths exceeding 100 fathoms. This maximum depth possibly was exceeded locally in some of the intramarginal troughs, like the Levis channel, which Ruedemann thinks may have been much deeper. However, the very common occurrence of thin beds of limestone conglomerate in the graptolite-bearing sediments of these troughs seems to militate very strongly against the assumption of great depths.

Effects of currents on deposition—Improbability of marine scour.—Some geologists, notably Willis,[25] endeavor to account for known local absence of sediments of certain ages in areas of continental seas by assuming "non-deposition and even scouring of bottoms . . . where they are swept by currents whose load is less than their efficiency." This view is based on such well known recent instances as (1) the reputed scour of the Gulf Stream where it flows across the marginal platform of the continent between Florida on the one side and the Bahamas and Cuba on the other; and (2), the stony, cleanly swept, submarine ridge which stretches between Scotland and the Faroe Islands and separates the north Atlantic and Arctic basins. Willis admits that non-deposition and marine scour is today, and has always been, an exceptional condition, "restricted to comparatively shallow waters, in the path of a relatively strong marine current." But, he goes on to say, "the epicontinental seas of the periods of great marine transgressions (Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Cretaceous of North America, for instance), opened channels across the continent, through which oceanic currents circulated as the Gulf Stream flows from the Caribbean to the

[25] Bailey Willis: Science, vol. xxxi, Feb. 18, 1910, p. 249.

Atlantic. Low lands bordering these seas and the deposits which accumulated in the deeper basins consisted in great part of fine calcareous ooze. Under these conditions non-deposition and marine scour have been favored on shallows along shores and in straits, and in any such places a corresponding hiatus must occur in the stratigraphic sequence." This suggestion attacks and seeks to supplant the more commonly accepted belief that a stratigraphic hiatus generally implies a corresponding time of emergence, and it discredits all the stratigraphic and faunal evidence on which minor oscillation of continental seas is based. The proposition is readily tested and I believe easily refuted.

The general improbability of marine scour being an important cause of even the minor discontinuities of sedimentation commonly ascribed (see Part II of this paper) to oscillations of the sea-bottom and to consequent migrations of the strandline is suggested at once when we consider (1) the almost universal shallowness of the continental seas, and (2) their usually limited extent. In such seas currents of the necessary efficiency could be developed only in narrow passages, or straits, connecting broad basins, and then chiefly when a great volume of water is required to replace that lost in the basins by evaporation. Disregarding the limited extent of the basins and admitting, for the sake of the argument, the probable tendency of strong oceanic currents to enter them, there yet remains the certainty that their strength must soon be diminished by bottom friction to merely gentle circulation in the island-studded interior seas. Tidal currents doubtless were effective in narrow, or merely shallow, passages connecting inland basins with the oceanic seas, but these likewise must soon have lost their efficiency.

Cases indicating local prevention of sedimentation and bottom scour by marine currents.—In a rather wide experience in the Paleozoic rocks of America I have met with no instance of simple interruption, or even diminution, of sedimentation in the interior continental basins that may be unquestionably ascribed to marine currents. Though numerous cases suggesting local channeling and dissection of tidal flats have been observed, only two instances of erosion that may with any show of reason be referred to marine scour were noted. One of these occurs within the Lowville limestone near Watertown, New York, the other on War Eagle Creek, in northwestern Arkansas, where the Boone sea, or some other agent, removed nearly 100 feet of older Waverlyan limestone before sedimentation was resumed.

Possibly current action may be responsible also for the absence of certain thin beds in the normal succession where submergence of the area is proved by the preservation of deposits of the age in question

in old fissures and caverns which had been excavated in the underlying rock during a preceding period of emergence. Such cases, however, are more commonly explained by assuming sedimentation and subsequent removal of the deposit by erosion except where it lodged in the protecting fissures and caverns. Though as a rule disinclined to admit considerable degradation in "negative" areas, this explanation can not always be successfully denied. Such a case, for instance, may be the very early Waverlyan deposits containing fish remains of the genus *Ptyctodus* found in enlarged joint planes in the Niagaran dolomites at Chicago. This region, namely, was subjected to subaerial agencies during a long period, extending from the early Waverlyan to at least the Pennsylvanian and probably to the present time. Another such case may be the remnants of Oriskany sandstone at Buffalo, New York. However probable, it may yet be contended that the evidence of blanket erosion is in neither case convincing. Such erosion is much more likely in the case of the remnants of Boone and Burlington limestone and Pennsylvanian shales deposited in and still filling Paleozoic sinkholes on the Ozark uplift.

But there are other cases—rare, it is true—of deposits occurring locally only in earlier solution cavities that are most probably not mere remnants of sheets otherwise removed by surface erosion. I have in mind two Ordovician caverns filled with later Ordovician shales that are not represented in the section on either side of the caverns. One of these is found in a railroad cut about 6 miles west of Saint Genevieve, Missouri, the other in a quarry at Darlington, Wisconsin. Being clearly near-shore occurrences, these instances of localized sedimentation suggest shore and tidal currents or wave action, or both, as prohibiting deposition except in depressions of the sea bottom. But, as said, such occurrences are very exceptional in Paleozoic seas.

There is reason to believe further that conditions favoring non-deposition and even scour occurred in certain submarginal troughs having wide-mouthed connection with permanent oceanic basins and through which large volumes of water may have been poured. Ideal examples of such troughs would be the early Paleozoic channels on the inner border of the marginal lands of the North American continent, like the Levis channel, which connected the Saint Lawrence embayment with the middle Atlantic somewhere near Delaware Bay; or like the Athens trough or channel, which is believed to have opened at the north into the Atlantic about Chesapeake Bay and at the south into the Mexican sea. Littoral, in fact bottom-dwelling faunas of any sort, scarcely existed in these troughs, the known fossils being almost entirely types

adapted to pelagic conditions. Indeed, the suggestion of currents locally prohibiting deposition is a welcome addition to the evidence on which these long channels or straits are inferred, since it affords a satisfactory explanation of the absence of graptolite-bearing shales in the areas that the channels had to cross in order to connect with the oceanic basins.

An adequate discussion of these channels and their relations to marine currents can not be undertaken here. It must suffice to say that the faunal evidence, which is abundant and requires an opening at either end, as well as continuous currents to transport the floating organisms, is in accord with the structural and stratigraphic phases of the problem. In such channels, therefore, currents capable of affecting the character and amount of deposits are not only admitted but averred. Neither have I any desire to question the effect of currents on the distribution of marine organisms. Indeed, I am convinced that in the oceanic waters themselves the distributing agent of paramount importance is found in the currents. (See also page 517.)

Current scour improbable in interior continental seas.—The case with respect to the broad inland seas is altogether different. Willis admits that currents competent to do the work in these inland basins are possible only under the supposition that channels, extending, in the case of North America, from the Gulf of Mexico completely across the continent to the Pacific and Arctic oceans, were opened at times of great marine transgressions. If they occurred at all, they must be exceedingly rare and perhaps in no case positively demonstrable. Sufficiently wide transgressions are indicated in most published paleogeographic maps, even in many of those recently issued in the bulletin of the Geological Society of America by Schuchert. But most of these maps are synthetic in that they cover two or more, often very different, stages of the shoreline. The more detailed our stratigraphic studies the more we are obliged to confine the continental seas to definitely limited basins. These continental basins are in communication with one or another of the oceanic basins, but the oceans themselves are only at rare times in communication by means of these interior basins. As to the invasions from the Gulf of Mexico, I doubt if these at any time mingled freely with waters coming in from either the Pacific or the Arctic sides[26].

The evidence on which great marine transgressions are postulated is, at least in its essential features, purely faunal. This evidence, moreover, usually rests on so-called cosmopolitan faunas. Indeed, the reputed

[26] The invasion diagrams shown on pages 346 and 347, being founded on synthetic paleogeographic maps, are necessarily, and for the same reasons, at variance with this opinion.

existence of these is said to be largely owing to such transgressions. The term cosmopolitan faunas sounds well, but when fairly analyzed it is but seldom found to have any basis in fact. Except in a very broad generic way, I question if there ever was such a thing as a cosmopolitan littoral or shallow-water bottom fauna. Some of these faunas doubtless attained great distribution in certain geologic times, but, aside from a few highly adaptable species and genera, they have always been limited by barriers of some kind to smaller or larger areas beyond which they could not spread. We have then comparatively few perhaps truly "cosmopolitan" shallow-water species and genera living with varying hosts of species whose geographic range is limited; but as to faunas to which the designation cosmopolitan may justly be applied, only those adapted to pelagic modes of existence could ever become so. Of such the Paleozoic graptolite faunas are notable examples.

There are some wide ranging bottom faunas and small groups of species that are of great service in correlating between eastern America and western Europe and others between western America and Eurasia, but I know of no fauna that lived at the same time, or at different times, in all of the oceanic basins of the northern hemisphere. When any considerable number of either land or marine species is common to two continents the fact argues strongly for land connection between them at such times; and given the continuous shoreline thus afforded the more vigorous elements of the bottom faunas migrated more rapidly than we can express it in any correlation table yet attempted. But only in rare instances did such faunas pass directly from the Atlantic into the Pacific or from the Pacific into the Atlantic. As to the occasional small associations of species that are so frequently cited as common to these great faunal realms, they are in every instance, especially the corals, of vigorous, long-lived types whose evidence in correlation paleontologists have learned from sad experience to view with suspicion. When critically studied the distant occurrences are usually found to be not only distinguishable from the species with which they have been identified, but they have often been shown to belong to very different geological ages. How often have authors thought they recognized middle Silurian corals in specimens since found to belong to middle Ordovician, Richmond, late Silurian, or even early Devonian horizons! Therefore, instead of being contemporaneous phases the local appearances of so-called cosmopolitan faunas are more probably either later or earlier stages of slowly modifying species, and consequently, if the mutations are not accurately discriminated, of little value in exact correlation. Quite certainly, too,

they owe their cosmopolitanism to other modes of migration than transcontinental currents.

Widely distributed species, whether pelagic or bottom dwellers, are of the highest service in determining contemporaneity of geologic events, but it is only the pelagic and semi-pelagic types that are dependable for exact correlation between distinct provinces and in proving the existence of unobstructed current highways. The last fact, considered in connection with the known rarity of pelagic faunas and species in the interior continental basins, is of vital importance on the question at issue. The other species, on the contrary, may occur in totally distinct continental basins; and for these it is only when a large percentage of a bottom-dwelling fauna is recognized from place to place that we are justified in assuming continuity of shoreline between them. The Lowville, for instance, indicates such a continuous shore and a corresponding uniformity of faunal distribution in the rudely triangular area (Ohioan province) between the mouth of the Mississippi on the south, Minnesota on the northwest, and western Quebec on the northeast. If there are deposits of this age to the west of this area, then they were laid down in a distinct basin, for the Lowville fauna is not found in them. In this and similar instances a few of the species are common to two or more otherwise distinct faunas, but these are the descendants of "cosmopolitan" types found in the Pacific and Arctic realms as well as in the Lowville proper which invaded the continent from the south.

Improbability of transcontinental marine currents shown by the geographic limitation of Mohawkian sediments and faunas.—A close analysis of the "late Black River and early Trenton fauna," whose distribution in North America, as mapped by Schuchert and Ulrich[27] [middle Ordovicic (lowest Trenton)"], suggests the greatest submergence of the continent known, proves a synthesis of several faunas differing not only in age but also in kind and to a considerable extent in their respective derivations. It includes (see accompanying map, figure 7), first, the Decorah shale fauna, a highly characteristic and therefore easily recognized association of species. This fauna is best known from its development in Iowa and Minnesota. It has been identified as far south as middle Tennessee, but, excepting one doubtful occurrence in northeast Tennessee, seems to be entirely absent in the Appalachian Valley. It is well developed on the east side of Ozarkia, but has not been seen on the other sides of this uplift. Still, it probably exists under cover of later deposits in an old

[27] Bull. Geological Society of America, vol. 20, pl. 58, 1910.

channel on the west side of Ozarkia, being known in central Oklahoma. Though entirely unknown in the western half of North America, in the

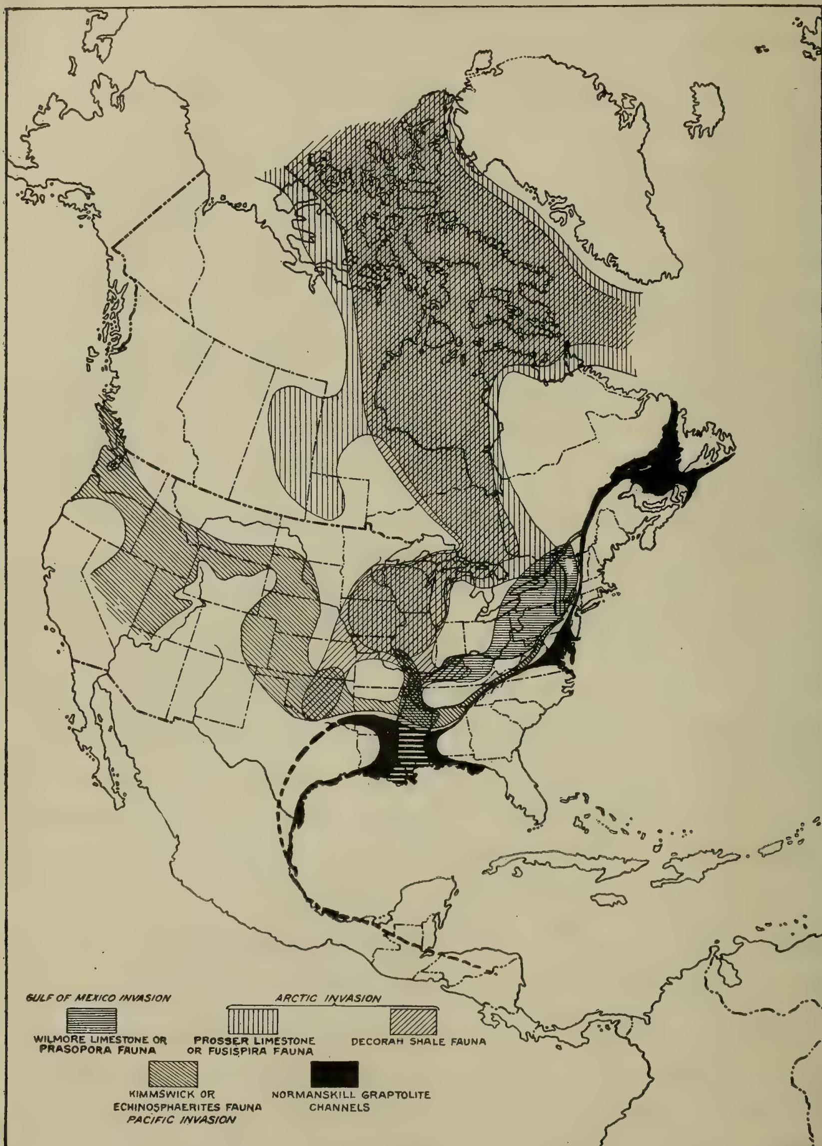

FIGURE 7.—*Map of North America, showing interlapping late Black River and early Trenton Invasions from the Arctic, Atlantic, Gulf of Mexico, and Pacific Sides*

eastern half, besides the areas mentioned, the Decorah fauna is recognized at many localities north of New York. With even a small collec-

tion of fossils there is never any doubt as to its identity from Missouri on to the head of Frobisher Bay, in Baffinland.

Next "the late Black River and early Trenton fauna" includes the Kimmswick limestone fauna, which, though clearly not a Gulf of Mexico fauna, is best developed in the middle stretch of the Mississippi Valley. From here it extends eastward, around the southern side of the Nashville island, into the Appalachian Valley, and westward, around the southern border of Ozarkia, to Colorado, where it is recognized in the Fremont limestone. In the Mississippi Valley it is unknown north of Missouri.

The third, evidently younger, fauna overlaps the northern edge of the Kimmswick in northeastern Missouri. This third fauna has its best development in the Fusispira bed of the proposed Prosser limestone in northern Iowa and southern Minnesota. It is not very typically developed in Oklahoma, and quite unknown in the far west; but in a north direction it is known in Baffinland. East from Minnesota we find it well developed, though perhaps occupying only a few inches of limestone, at the base of the Trenton in northern Michigan, Ontario, Quebec, New York, and northern New Jersey. In the Mohawk Valley, in New York, the bed containing the fauna is very thin and only locally present. In New Jersey it wedges out southwardly, with the rest of the Jacksonburg limestone, toward the head of an old bay into which this formation extends from eastern New York.

The fourth fauna included in the synthetized late Black River and early Trenton fauna differs greatly from the others in kind and derivation. While the first and third doubtless invaded from the north probably by way of Hudson Bay, and the second may have come from the Pacific, this fourth assemblage is made up mainly of species that must have invaded from the south or east. This is the *Praspora simulatrix* and *Mesotrypa quebecensis* fauna, known from Quebec and Ontario to middle Tennessee. It is well developed in the Wilmore formation of Kentucky and also in the lower part of the Trenton limestone in New York; but in the upper Mississippi Valley, in Oklahoma, in the far west, and to the north of Ontario it is wholly unknown.

Finally, it includes two other faunas, one observed at a few places between Nevada and Alaska, which can not be exactly correlated with any of the other four. Its age is indicated only in a general way as late Black River. The other, or sixth, is the Maclurina fauna of the Galena dolomite. Whether a little older or younger than the fourth or Wilmore fauna has not been decided.

Now, each of these faunas contains species common to two or more, but in each again the majority of the species is peculiar to its special

fauna. Further, with the exception of a small percentage of species, most of them of wide, possibly cosmopolitan range, the first three faunas, which invaded the continent from the north and west, are entirely different from those of the fourth fauna, which invaded from either the Atlantic or the Gulf of Mexico.

In view of the fact that the first or Decorah shale fauna maintains its essential characteristics from Missouri to Baffinland it does not seem reasonable to suppose that it could have been so changed as to be unrecognizable in the Appalachian Valley, in Colorado, and generally in the western part of the continent where Black River-Trenton faunas are known. Nor can we believe this of the third or Prosser limestone fauna, which likewise is recognized in Missouri and Baffinland, and is typically developed in New York, New Jersey and Canada, but which has not been observed west of the Mississippi Valley nor south of the Ohio. Neither has it been recognized in the Appalachian Valley south of New Jersey. It would be even less reasonable to assume that the two southern faunas, that is, the second and fourth of these really very different faunas on which the oft-asserted great early Trenton submergence is so insecurely based, suddenly lost their identities beyond the areas in which they are easily recognized. On the other hand, if we admit for a moment the possibility of their contemporaneity and the continuity of the waters in which they lived what possible reason might be advanced to explain why these northern and southern faunas failed to mix freely in the middle ground?

This being a time of great sea transgression when, according to Willis's theory, the continental seas were swept by strong currents, we ask ourselves, is it possible that these currents were so capricious that when the first (Decorah) and third (Prosser) faunas prevailed in the middle and northern areas where we now find them the currents prevented deposition in the south? Or that when the presence of the second (Kimmswick) and fourth (Praspora simulatrix) faunas were being recorded in the south the currents prohibited sedimentary records in the north? What possible reason could have occasioned such extraordinary vacillation of current efficiency? Or, to go further, on what grounds might we conceive of marine currents that could sweep cleanly the basins of half a continent and permit unimpeded deposition in the altogether similar shallow seas on the other half?

If we did not know from actual superposition of the beds in eastern Missouri that the Kimmswick fauna intervenes between the first and third and that in New York the fourth succeeds the third, the anomalies

of distribution might not be so obviously fatal to Mr. Willis's suggestion. But with this knowledge in hand, supplemented by the further fact that the two boreal faunas alternate with a probably Pacific and a Gulf of Mexico or an Atlantic fauna, all grounds for the proposition are obliterated. According to the evidence, we are forced to the conclusion that currents had nothing to do with the case. On the contrary, we must assume that these middle Mohawkian faunas represent four distinct and in part, if not for the whole of each, successive invasions of shallow basins on a nearly base-leveled, gently oscillating continental surface. Further, of we admit partial contemporaneity of the boreal and southern invasions, the final confluence of the basins must, even at its maximum, as is shown by the continued integrity of the respective faunas, have been very inconsiderable. Otherwise, a decided mingling of the faunas must have resulted. Obviously, then, without free communication between the basins, "channels across the continent, through which oceanic currents" might have circulated, were impossible.

Evidence of the graptolites on currents in continental basins.—The geographic distribution of the Eopaleozoic graptolites offers another strong argument against the hypothesis of transcontinental currents in the interior basins. I shall cite only the case of the Normanskill graptolites because these flourished in the same period though earlier than the "late Black River and early Trenton" submergences here chiefly considered. Besides, the other graptolite faunas, especially the Levis, lead to similar inferences. The Normanskill fauna, which comprises little besides graptolites, occurs in great development in the shales of the Levis and Athens troughs, respectively the northern and southern extensions of the eastern parts of the Appalachian Valley. It is abundant also in one of the shales of the similar Ouachita trough in Arkansas and Oklahoma. The same fauna is found also in Great Britain and Sweden and is recognized in Australia, on the opposite side of the globe. Obviously, this is a truly cosmopolitan pelagic fauna whose great dispersal is owing chiefly or solely to transportation by oceanic currents.

In North America the Normanskill graptolite fauna is confined to strips of shale just west of the Chilhowee-Green Mountain barrier of Ulrich and Schuchert. The age of the shale has been variously estimated. For many years it was thought to be the same as the Utica but now it is known to be older. Ruedemann and others regard it as middle Trenton and perhaps most geologists, Willis among them, now view the Normanskill shale as a nearer shore phase of supposedly contemporaneous limestone formations farther west. That it can not be this is proved con-

clusively, as I think, by the character of the faunas found respectively in the shales and in the limestones. Granting, for the sake of the argument, that they are contemporaneous and that the shore was to the east of the shale, we have the anomalous condition of a pelagic graptolite fauna hugging the shore while the true sublittoral and shallow water fauna is confined to assumed deeper waters farther out. Aside from the great improbability of such a reversal of the normal condition, it is inconceivable that the floating graptolites, which are not dependent on either the depth of the water or on the kind of bottom, should be so strictly confined to the Normanskill shale that not even an occasional straggler is to be found in the limestones. Now, it seems impossible that these graptolites should be entirely absent in the limestones only a few miles to the west if the shale was laid down at the same time and in the same basin. That the graptolites when they were carried into the continental seas at all did extend as far westward as the sea of the time is suggested by the occurrence of typical Utica species as far away from New York as Cincinnati, Ohio, a locality very near the extreme western edge of the Utica transgression.

On such grounds I long ago reached the conclusion that the Normanskill represents a time when the more inland areas with Stones River limestones were emerged; and, as is brought out in a later part (see page 555, the soundness of the opinion has since been proved by unquestionable stratigraphic evidence. Under this conception, of course, the absence of the Normanskill graptolites except in the narrow Appalachian troughs, to which the marine waters in southeastern North America are supposed to have been confined at this time, is at once explained. And as these restricted Normanskill channels were included in the synthetic "late Black River and early Trenton submergence" they may be added as another distinct stage of the continental seas to the several stages already described.

In order that the theory of interruption of deposition being often due to current scour might be fairly tested, I have selected the "transgression," which by general consent is accepted as the greatest known in geological history, hence the one which offers conditions more favorable to the efficient operation of transcontinental currents than any other transgression now recognized. If the theory fails in this case, as we have seen it does, it seems certain that it must fail also in all the others. There is no reasonable chance for a great transcontinental current in the Cambrian transgression; and even less in those of the Silurian and Devonian periods. As for the Waverlyan and Tennessean transgressions, these did not extend north of the United States. Hence great oceanic currents

were impossible in these periods, and the frequent local as well as general interruptions of sedimentation indicated by comparative studies of the rocks of these ages in the interior areas must be ascribed to other causes. But there are other tests which should be applied before the theory is entirely discredited.

Progressive overlap structure opposed to theory of current scour.—Perhaps the strongest argument against the efficiency of currents in preventing deposition in the interior continental seas is found in stratigraphic overlaps. These are very common on the flanks of all the median areas of frequent uplift. They are excellently shown on the gently sloping sides of the Adirondack, Wisconsin, Cincinnati, Nashville, and Ozark islands of Paleozoic ages. Careful study of the various instances enables us to reconstruct even the minor indentations of the shores of these islands.[28] In most cases, even where exposed through long ages to subærial conditions, the proof of the overlap shown by the progressive increase in extent of the successive beds has not been obliterated by erosion. Sometimes, indeed, the top bed, perhaps only a few inches in thickness, may be traced to the extreme edge of the slowly advancing sea.

These overlaps show that the Paleozoic interior lands were very low, and, as we may justly infer, the intervening depressed spaces which were occupied by the seas, correspondingly shallow. The great frequency of overlapping formations—I venture to say that all sedimentary formations overlap toward the "positive" areas—shows that the general relief of the median regions was never so great in Paleozoic time as at present. In such shallow, slowly advancing seas, the advance being ever recorded by overlap of deposits, strong currents are impossible; that they were developed in later stages, in which, it might be urged by exponents of the theory, submergence advanced, although the area receiving deposits was restricted, seems altogether improbable. In my opinion the suggestion is not only improbable but is proved impossible by the progressive overlap phenomena, which, in so far as the record is accessible, are as generally developed in these restricted formations as in the more extended formations preceding them.

The idea suggested by the observed fact that nearly all of the formations that indicate extensive submergence have an overlapping structure may be expressed somewhat differently. Thus, it is clear that the more extensive the submergence the nearer we approach the condition required for the generation of transcontinental currents. Hence the effort of the presumed currents, in the way of prohibiting deposition and in scouring

[28] Geol. Atlas, U. S., Columbia Folio.

the bottom, would necessarily be increasingly exerted in the later maximum stages of the submergences. The facts, however, invariably indicate the opposite condition of simple progressive overlapping of deposits.

Geologic literature is full of statements implying continuous deposition in sections that have since been shown on incontrovertible evidence to include greater or smaller hiatuses. Convincing physical evidence of subaerial decay and corrasion is often difficult to find in such obscurely marked instances of interrupted sedimentation; but in my own experience, the break indicated by the fossils seldom failed to be substantiated by the discovery of unconformable stratigraphic relations and as a rule of evidence pointing to land conditions.

In this connection it is important to note, first, that the time value of the hiatus is in no wise suggested by the degree of the unconformity or by the relative coarseness or abundance of clastic matter at the contact. Both of these criteria of interrupted deposition may be exceedingly obscure in hiatuses spanning two or more periods of time, while, on the contrary, they may be strongly expressed in cases of relatively brief duration. It is largely a matter of geographic relation to belts of folding and of consequent vigorous erosion whether the unconformity is strongly or but weakly developed. Regarding the latter condition, which prevails in the median areas of the continent, numerous striking examples might be cited. I have more particularly in mind many sections in Missouri and Arkansas in which beds ranging from late Devonian to early Pennsylvanian rest on Ozarkian, Canadian, or early Ordovician. In these sections the physical criteria of the great hiatus are generally so inconspicuous that they have been more often overlooked than noted. Indeed, without fossils the importance of the break could not be established as greater than many relatively insignificant contacts above and beneath it.

It is important further to note that the formations which intervene on the flanks of the uplifts, especially on those of Ozarkia, between the Ozarkian and Pennsylvanian systems can in nearly every instance be shown to have an overlapping structure. As stated, this structure is a fatal physical objection to the application of the theory of current scour in explaining the absence of the lower beds of the overlapping formation, because in the restricted earlier stages the possibility of strong transcontinental marine currents was more remote than in the final stage of the transgression, which, instead of commonly failing to deposit, usually did so more regularly than the early stages. Moreover, the "progressive" feature of the overlaps would have been impossible, because if scour had occurred the overlaps must have become "regressive," which they are not.

As to the possibility of the existence of deposit-prohibiting currents, and of their efficiency as erosion agents, in geological ages wholly unrepresented by accessible deposits on the flanks and summits of interior areas of uplift, no other evidence than that afforded by the fossils can fairly be considered. The essential features of this evidence were brought out in discussing the Black River-Trenton submergences. Taken as a whole, though it may be well to lay particular stress on the provincial distinctness of the faunas (whether regarded as exactly contemporaneous or not), the faunal evidence is unqualifiedly opposed to the suggestion of current efficiency being responsible for discontinuties of sedimentation in continental seas, except under such very unusual conditions as were mentioned near the beginning of this discussion.

Having, as I believe, fairly weighed Mr. Willis' suggestions concerning marine scour and found them wanting on the unqualified evidence of both the organic and the physical criteria, I feel justified in continuing to regard agelong interruptions of marine deposition in continental basins as indicating corresponding emergences. (See also pages 448-467.)

The Stratigraphic Column

DEVELOPMENT OF THE AMERICAN PALEOZOIC COLUMN

Review of the classifications of other authors.—Going no farther back in the history of American stratigraphic classification than 1862, the year in which Dana issued the first edition of his Manual of Geology, a work that in its successive editions may be fairly claimed to express, though somewhat conservatively, the status and progress of the science, the accepted major divisions of the Paleozic were as follows: (1) Silurian age, divided into Lower Silurian and Upper Silurian, and each of these into three periods, the former into Potsdam, Trenton, and Hudson, the latter into Niagara, Salina, and Lower Helderberg; (2) Devonian age, divided into five periods, Oriskany, Upper Helderberg, Hamilton, Chemung and Catskill; and (3) Carboniferous age, with three periods, sub-Carboniferous, Carboniferous and Permian. This classification was essentially that of Hall, published a few years earlier in his Iowa report, and less in accord with the classification now generally accepted than were those published by De La Beche in 1851, and Lyell in 1855. Both of these British authors recognized five major divisions, distinguishing a Cambrian below and a Permian at the top.

In 1875 Dana modified his classification by recognizing a Primordial or Cambrian period at the base of the Silurian, the Canadian and Trenton periods constituting the middle and upper parts of the Lower Silurian. The Upper Silurian, Devonian and Carboniferous are the same as in 1862,

except that the base of the Devonian is drawn at the top of the Oriskany, this formation being now at the summit of the Silurian. The result after these changes, when viewed in the light of present knowledge, appears retrogressive rather than progressive.

Dana's final classification was published in the 1896 edition of his Manual. Several changes, all progressive, are now apparent. The Paleozoic is divided into two parts, Eopaleozoic and Neopaleozoic. The former comprises two systems, the Cambrian with three subdivisions—Lower, Middle and Upper, and the Lower Silurian; the latter is divided into three systems—the Upper Silurian, Devonian, and Carbonic.

The most important of the changes in the 1896 edition is the recognition of the great break between the lower and upper Silurian and the coordinate rank assigned to each of these two divisions. In so far it admits the truth of Sedgewick's original contentions as opposed to those of Murchison. The acceptance of a Cambrian system beneath the Lower Silurian was perhaps a no less significant admission. Of minor import is the return of the Oriskany to the base of the Devonian.

Except that the name Ordovician, proposed by Lapworth in 1879, is used in place of Lower Silurian, the classification of the Paleozoic adopted in 1903 by the committee of leading American geologists invited by the U. S. Geological Survey to revise American stratigraphic nomenclature, is practically the same in its major divisions as that of Dana, 1896. So far as the number and in general the components of the Paleozoic systems are concerned, no important change was suggested in the eleven years following the issue of Dana's latest classification. The latterly increasing practice of the New York Survey of using their old names, Champlainic instead of Ordovician, and Ontaric instead of Silurian, is not taken into account, since it differs solely in the matter of nomenclature.

In 1907 appeared the two volumes, entitled "Earth History," of Chamberlin and Salisbury's work on Geology. The progressive character of this work is indicated by the adoption of Proterozoic, an era of sedimentation between the Archeozoic beneath and the Paleozoic above. Again it is shown by the separation of the Carboniferous into three systems, the Mississippian, the Pennsylvanian, and the Permian, and by the separation of the Comanchean from the upper or true Cretaceous, thus dividing the Mesozoic into four systems where formerly there were but three. In the Cenozoic, on the contrary, Chamberlin and Salisbury suggest a reduction in the number of systems or periods, the trend of their argument being that three—the Eocene, Miocene, and Pliocene—are all that are justified by the application of criteria employed in the differentiation of the older systems.

		New York Survey, 1899–1908	
I Tertiary	E		
	N		
	C		
	M		
II	E		
III Secondary	C		
	W		
	O		
	L		
	N		
	M	Paleozoic	
	C		Carbonic
	O		Devonic
IV Transition	S		Ontaric
	O		Champlainic
			Cambric
		Archean	

[a] Ne ENCLATURE FROM 1837 T

Lyell, 1837	New York State Survey, 1841–1843	Phillips, 1841–1855	De La Beche and Lyell, 1851–1855	Dana, 1862	Dana, 1896	New York Survey, 1899–1908	U. S. Geological Survey, 1903–'4–1908	Chamberlin & Salisbury, 1907	Schuchert, 1910	Proposed Classification, Ulrich, 1911
Tertiary: I Recent period Newer Pliocene Older Pliocene Miocene II Eocene	VIII Quaternary VII Tertiary	Tertiary or Cenozoic series (with seven subdivisions)	Tertiary or Cenozoic: Recent Pleistocene Pliocene Miocene Eocene	Age of Man Cenozoic: Post-Tertiary Tertiary	Cenozoic: Quaternary Tertiary		Cenozoic: Quaternary { Recent, Pleistocene Tertiary { Pliocene, Miocene, Oligocene, Eocene	Cenozoic: Pleistocene, Pliocene } ? Miocene Eocene	Tertiary or Cenozoic: Neogenic Eogenic	Cenozoic: Neogenic { Recent, Pleistocene, Pliocene, Miocene Eogenic { Oligocene, Eocene, Paleocene
Secondary: Cretaceous Wealden Oolitic or Jura Lias New Red sandstone	VI New Red sandstone	Secondary or Mesozoic series: Upper Mesozoic: Chalk, Greensand Lower Mesozoic: Wealden, Oolite, Lias, Poikilitic series	Secondary or Mesozoic: Cretaceous Jurassic Triassic	Mesozoic: Cretaceous (Wealden) Jurassic Triassic	Mesozoic: Cretaceous Jurassic Triassic		Mesozoic: Cretaceous Jurassic Triassic	Mesozoic: Cretaceous Comanchean Jurassic Triassic	Mesozoic: Cretacic Comanchic Triassic-Jurassic	Mesozoic: Cretaceous Comanchean Newark or Jura-Trias Pennsylvanian
III Magnesian limestone Carboniferous Old Red sandstone Transition: IV Silurian Older than Silurian	V Carboniferous IV Old Red sandstone III New York[a]: Erie, Helderberg, Ontario, Champlain II Taconic	Primary or Paleozoic series: Upper Paleozoic: Permian, Coal series, Mountain limestone Middle Paleozoic: Old Red or Devonian series Lower Paleozoic: Ludlow, Wenlock, Caradoc, Llandeilo, Festiniog, Bangor	Primary or Paleozoic: Permian Carboniferous Devonian Silurian Cambrian	Paleozoic: Carboniferous Devonian Silurian	Paleozoic: Neopaleozoic: Carbonic, Devonian, Upper Silurian Eopaleozoic: Lower Silurian, Cambrian	Paleozoic: Carbonic Devonic Ontaric Champlainic Cambric	Paleozoic: Carboniferous { Permian, Pennsylvanian, Mississippian Devonian Silurian Ordovician Cambrian	Paleozoic: Permian Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian	Neopaleozoic: Permic Pennsylvanic Tennesseic Mississippic Devonic Siluric Paleozoic: Cincinnatic Ordovicic Canadic Ozarkic or Cambric Acadic Georgic	Neopaleozoic: Tennessean Waverlyan Devonian Silurian Eopaleozoic: Ordovician Canadian Ozarkian Cambrian
Primary	Primary	Hypozoic	Primary	Azoic	Archean	Archean	Algonkian Archean	Proterozoic Archeozoic		Proterozoic Archeozoic

[a] New York system with 28 formational units.

DEVELOPMENT OF GEOLOGICAL COLUMN AND OF STRATIGRAPHIC NOMENCLATURE FROM 1837 TO 1911

The classification just published by Schuchert[29] goes much farther in the way of dividing up the Paleozoic systems. First, he divides the Paleozoic into two eras, restricting this name to the lower era and adopting Dana's Neopaleozoic for the upper. The Paleozoic then is divided into six systems, the three lower of which (Georgic, Acadic, and Ozarkic or Cambric) correspond to the old Cambrian, and the three upper (Canadic, Ordovicic, and Cincinnatic) to the old Ordovician or Lower Silurian. The Mesozoic is as in Chamberlin and Salisbury, except that the Triassic and Jurassic are merged into a single system; and the Tertiary is divided into only two systems instead of three to six, as was the custom previously. Although Chamberlin and Salisbury recognized the high value of diastrophic criteria in stratigraphic classification, Schuchert was the first to publish a scheme based wholly on one phase of diastrophic activity, namely, the displacements of the strandline. The principle followed by Schuchert doubtless is the most reliable so far discovered, but his method of determining its operation is believed to have been faulty and the result correspondingly inconsistent. Using only the stages shown in his paleogeographic maps, he plotted a curve indicating the alternating advance and retreat of the strandline according to which he then drew his systemic boundaries. Obviously this evidence is incomplete, since it includes only the stages mapped by him and disregards the often more important sea withdrawals that occurred in the unmapped intervals. Besides it is thought that the other diastrophic criteria were not sufficiently considered.

Comparing the last two columns of the accompanying table, it will be observed that our respective arrangements agree down to the base of the Silurian, except in two important features and one relatively unimportant, namely: I begin the Mesozoic farther down in the scale; second, I discard the Permic and divide its formations between the Pennsylvanian and the Jura-Trias, and, third, prefer the term Waverlyan to his restricted Mississippic. The greatest difference is found in the subdivisions of the Eopaleozoic era, Schuchert recognizing six periods, while my scheme has, like the succeeding Neopaleozoic and Mesozoic, but four. The reasons for these differences will be discussed in detail in Part III, which concerns itself chiefly with the taxonomic aspects of stratigraphy.

Diminishing imperfections of the geological record.—It will be observed from the foregoing very brief account and the accompanying table, that while the broader elements of the classification of the Mesozoic and

[29] C. Schuchert: Paleogeography of North America. Bull. Geological Society of America, vol. 20, 1910, p. 606.

Cenozoic rocks have remained practically fixed in the past fifty years and more, those of the Paleozoic have been in a state of almost continual modification. The Paleozoic column, though occasionally suffering reversals, has on the whole grown steadily; and this growth has not been solely through the addition of new stratigraphic units. No, geologists have learned to detect discontinuities in sedimentation where formerly none was suspected. In a majority of instances these hiatuses doubtless represent long periods of land emergence. Locally, the physical evidence for this interpretation is often exceedingly obscure. Indeed, considered by itself, the physical evidence of unconformity in many cases may seem quite inconclusive, even when the corroborative evidence of fossils and the criteria of overlap or of retreating seas proves the break to have a great time value.

That the accessible marine and land deposits nowhere comprise a continuous record of geological history none will deny. The principle is so firmly rooted and has been for so many years, that it would be a waste of time and opportunity to argue the point. Yet, despite the general acceptance of the principle, much difference of opinion prevails concerning the aggregate and individual extent of the imperfections. Some probably would maintain that the imperfections are largely due to incomplete observation and study of the stratigraphic record, that only a small part of the continental marine sediments of the earth has been carefully investigated, and that when our observations have been extended so as to embrace all the accessible deposits the imperfections will have become practically negligible. So far as the biologic record is concerned, this optomistic view is probably justified, since with time the unflagging efforts of investigators doubtless will fill most of the gaps occasioned by regional variations in biologic development; and, finally, the time gaps will also have been largely accounted for by refined methods and practice of stratigraphic correlation. But past experience suggests the futility of the hope of bridging all the gaps, or even of fully appreciating their significance.

With the advance of knowledge the gaps are lessened by the intercalation of previously unrecognized fragments of the record, but the gaps themselves, however minimized, are yet multiplied. It is commonly found that the intercalated beds still fail to completely fill the gap, so that instead of the previously known hiatus two or more smaller gaps remain to be accounted for.

The true time significance of a stratigraphic hiatus is never appreciated until beds corresponding to it in whole or part are discovered. The faunas, in the absence of information respecting the unknown stages of

development, can give no adequate conception of the missing intervals; and the physical evidence of discontinuities of sedimentation is even more uncertain. An unconformity indicating absence of sediments of four or five consecutive periods may be no more readily discernible than another representing a relatively insignificant time interval. In fact, the longer the interval of emergence the more complete the baseleveling, and consequently the less conspicuous the contact irregularities. No better illustrations of the principle can be found than those briefly mentioned in an earlier part of this paper in discussing the effects of currents on deposition in continental seas and in describing certain overlaps (see pages 305 to 311, 449 to 467, and 526 to 532).

Additions to the Paleozoic column since 1850.—Since the Potsdam sandstone was thought to be the oldest fossiliferous sedimentary rock many thousands of feet of older fossiliferous deposits have been found to which the name Cambrian is now almost universally applied. Even yet this "Lost Interval" is far from being wholly accounted for, the several intercalated stratigraphic units being in most cases separated from each other by more or less clearly indicated gaps of undetermined time values. Similarly, the Eopaleozoic ages following the Potsdam have been expanded so that instead of an insignificant 200 feet of Calciferous between the Potsdam and the Chazy we know that elsewhere in America this interval comprises deposits aggregating in thickness to no less than 7,000 feet of limestone and dolomite. And the end is not yet, for in the thickest sections of this interval we still encounter undeniable evidence of repeated interruption of sedimentation.

The Ordovician expansions are scarcely less in value than those of the older systems of the Eopaleozoic era. We have learned that the Saint Peter sandstone represents the median to upper part of an unnamed group or series of sediments of considerable though not yet accurately determined time value, that followed the Canadian and preceded the first of the Chazyan deposits. Then the Stones River and Blount groups, together comprising the Chazyan series, have been shown to have an aggregate thickness in the Appalachian Valley more than four times as great as that of the three divisions of the series in the Champlain Valley. Finally, the lower Mohawkian Black River group, which is thin and very unequally distributed in New York, is now known to be represented by deposits in east Tennessee and the Mississippi Valley, having a total thickness of more than 1,000 feet. Even the upper Mohawkian or Trenton group comprises a greater thickness of limestone than was suspected twenty years ago.

The additions to the post-Ordovician parts of the stratigraphic column in the past fifty years have been less than in the older rocks. Obviously, the reason for this is that the fullest records of the older deposits are found in regions that have been comparatively difficult of access and in which, moreover, the stratigraphic relations of the several beds are often much obscured by complicated structure. Still, important accessible additions to the Silurian, Mississippian, and Tennessean systems have been made. The expansion of Silurian time we owe chiefly to refined correlations of post-Niagaran deposits in New York, Maryland, Ohio, and Michigan by Clarke, Schuchert, Hartnagel, and Grabau in the past fifteen years. Through their efforts the aggregate thickness of deposits in American continental seas between the top of the Guelph and the top of the Manlius has been more than doubled. Revision of the evidence bearing on the time relations of the Niagaran formations will necessitate further expansion of the Silurian by showing that nearly the whole of the dolomitic limestones of this age in Wisconsin belong above the horizon of the Rochester shale of New York. Finally, the reference of the Richmondian deposits to the base of the Silurian does not expand this system merely at the expense of the Ordovician, but actual expansion of the Richmondian interval itself has occurred through study of deposits of this age in the Mississippi Valley and on the Island of Anticosti.

Very little has been added to the Devonian except by transference of the Helderbergian from the Silurian and in the way of greater thickness of some of the later deposits in the Appalachian Valley than had been known before. However, a greater length of Devonian time than is indicated by the relatively clastic character of a large proportion of the sediments of this period in southeastern America is suggested by the reported extraordinary thickness (6,000 feet) of limestone in Nevada referred by Walcott and others to this system. Though some of this great mass may not be of Devonian age, it yet seems certain that the deposition of the remainder required sufficient time to insure apparently greater than average time value for Devonian deposition in continental basins.

The great duration of the Waverlyan, Tennessean, and Pennsylvanian periods could not be appreciated in the early days when our knowledge of these ages rested almost entirely on the stratigraphic record found in the Mississippi Valley and when the whole of this was comprised in a single Carboniferous system. The more complete records subsequently determined in the Appalachian region added much and in a manner prepared us for the proof of the enormous time involved in these periods that investigations in the far west has brought out. The aggregate

thickness of "Carboniferous limestones" in the Cordilleran troughs seems far too great for a single system. Indeed, when the deposits in the several troughs have been properly correlated, I do not doubt that evidence of oscillation and consequent general and local discontinuities of deposition will be found that will sufficiently increase the already great sedimentary record to fully warrant the three systems into which it is proposed to subdivide it.

THICKNESS OF "PALEOZOIC" SEDIMENTS IN AMERICA

So far as determined, the maximum thickness of marine deposits in American continental seas from the beginning of Cambrian to the close of the Pennsylvanian aggregates approximately 75,000 feet. This total includes deposits of all kinds, and therefore gives neither a true idea of the time involved nor a satisfactory means of comparing the time values of the successive systems. Manifestly, the rate of deposition is widely different for the various kinds of sediments. That of the clastic deposits, further, is exceedingly variable, being greatly influenced by temporary and local conditions. The rate of limestone deposition probably also varied considerably according to its origin, its purity, and the probable variability of conditions favoring chemical precipitation. Still, it is the only kind of marine sediment for which we may reasonably assume an average rate of deposition sufficiently uniform to warrant its use as a basis in determining the respective time values of stratigraphic units. Therefore, eliminating as much as possible the clastic deposits and considering in their stead (1) the known calcareous sediments regarded as corresponding in age to certain clastic sediments, and (2) the probable limestone value of the sandstones and shales, of which no equivalent calcareous deposits are known (somewhat arbitrarily assumed as 7 to 1), the total thickness of Paleozoic marine sediments corresponds to something like 43,000 feet of limestone. This sum is divided among the nine systems about as follows: Cambrian 8,000 feet, Ozarkian 6,500, Canadian 4,200, Ordovician 5,700, Silurian 3,000 to 4,500, Devonian 6,000, Waverlyan 1,000, Tennessean 2,500, Pennsylvanian (including lower Permian) 4,600.

The great thickness of 8,000 feet or more of Cambrian limestone is computed from Cordilleran sections recently published by Walcott[30]. As given by this authority the total thickness of the Cambrian in Utah is not far from 19,000 feet. The lower 12,000 feet consist almost entirely of quartzites and siliceous shales. Considerable limestone is

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[30] C. D. Walcott: Cambrian geology and paleontology, No. 5. Smiths. Miscell. Coll., vol. liii, 1908, pp. 167-230.

found in the lower Cambrian in the vicinity of Silver Peak, Nevada, where nearly 6,000 feet of beds referred to this division are exposed. The middle Cambrian in the House Range and Wasatch Mountains is nearly 5,000 feet thick and composed almost entirely of limestone. Of the limestones referred by Mr. Walcott to the upper Cambrian, aggregating in different sections from 1,227 to 3,590 feet, a large part is thought to represent the proposed Ozarkian system. According to Mr. Walcott there is no physical break between the top of the "upper Cambrian" and the limestone referred by him to the Ordovician. The break at the top of the "middle Cambrian," however, seems generally well marked.

The aggregate thickness of 6,500 feet ascribed to the Ozarkian system is a conservative estimate made up of 4,000 feet of Knox dolomite in the western part of the valley of east Tennessee plus about 2,500 feet of overlying and underlying dolomites seen in Alabama. As shown on pages 633 to 639 the aggregate thickness of calcareous Ozarkian deposits in the southern Appalachian Valley alone seems to be nearly 8,000 feet. More detailed sections will be given in one of a proposed series of papers on local stratigraphic subjects.

The thickest continuous section of calcareous deposits belonging to the Canadian system is at Bellefonte, Pennsylvania, where the total thickness is not less than 4,200 feet. There is reason to believe that still older deposits of this period are included in the Levis shale of the Saint Lawrence Valley and possibly also younger beds in the Arbuckle limestone of Oklahoma.

The total of 5,700 feet of Ordovician limestone is made up chiefly from deposits in the Appalachian Valley. The principal exception is the basal series comprising the Saint Peter sandstone. This is well developed in the Mississippi Valley, especially in northern Arkansas, but so far is unknown in the Appalachian Valley. This basal series is given a limestone value of 300 feet, though it probably represents a much greater time interval than this amount implies. The oldest of the Ordovician deposits in the Appalachian Valley is the Stones River limestone, of which 1,300 feet are seen at Martinsburg, West Virginia, all of it presumably younger than the Saint Peter. This limestone is followed by the Blount group of limestone shale and sandstone with a maximum thickness of at least 3,500 feet observed in Grainger and Blount counties, Tennessee. The limestone value of this group is not less than 1,500 feet. Next comes the Black River group of limestones comprising the equivalents in northeastern Tennessee of the Lowville and Watertown limestones of New York, of the upper Chambersburg limestone of Pennsylvania, and

the Kimmswick of Missouri, with a combined thickness of at least 1,500 feet. This is followed by 600 feet of Trenton limestone, as shown in central Pennsylvania and Tennessee, and finally by the Cincinnatian limestones and shales, estimated at about 500 feet.

The Silurian is probably underestimated rather than overestimated at 3,000 feet. It may be all of 4,500 feet. The Richmondian, according to present correlations, is not less than 1,000 feet, the most complete section being on the Island of Anticosti. Counting the mainly clastic deposits of the Appalachian Clinton formation as corresponding in aggregate value to about 400 feet of limestone and the Waukesha, Racine, and Guelph dolomites in east Wisconsin at 600 feet, the Niagaran is estimated at about 1,000 feet. But according to the evidence brought in by Kindle from the Porcupine River section in Alaska,[31] this amount falls far short of the truth. Kindle, namely, estimates the Niagaran dolomites in this region at about 2,500 feet. The Cayugan, judging from the irregularly distributed deposits in central Pennsylvania, New York, Ohio, and Michigan, seems to have an aggregate thickness representing something like 1,500 feet of limestone.

The great thickness of 6,000 feet of Devonian limestone is found, according to descriptions by Walcott and Hague, in the Eureka district of Nevada. That this thickness is probably not too great for the whole of Devonian time is suggested by the 1,200 feet of Helderbergian and 550 feet of Oriskanian limestone occurring, as described by J. M. Clarke, in the Gaspe region of Canada.

The accessible depositional records of the Waverlyan and Tennessean systems are both thinner than any of the preceding systems. As used in this paper, the Waverlyan comprises the beds beginning with the Chattanooga shale and ending with the Keokuk. The Waverlyan seems to be a time of considerable interruptions of sedimentation, and the great difference between the last of its faunas and the first of the Tennessean argues for an especially long interruption at its close. This point will be further discussed in Parts II and III. The maximum aggregate thickness of accessible Waverlyan sediments, considered on the basis of limestone values, is placed provisionally at 1,000 feet. It may be that this figure is too high, but it is more likely to prove too low. In the Mississippi Valley the succession of limestone deposits of the Waverlyan system scarcely exceeds a total of 500 feet, but the evidence of repeated interruptions of the process of deposition is convincingly shown in both the Kinderhook and Osage series of limestones. Until

[31] E. M. Kindle: Journal of Geology, vol. 15, 1907, and Bull. Geological Society of America, vol. 19, 1908.

accurate correlations with the pre-Pennsylvanian "Carboniferous" limestones of the Cordilleran troughs shall have been made it can not be said to what extent the gaps in the known record of the Waverlyan are bridged over in such areas of relatively continuous deposition.

The 2,500 feet of Tennessean limestone are made up from the great thickness of Newman limestone and the estimated limestone values of the calcareous Pennington shale and of the more clastic Princeton and Bluestone formations in the Appalachian Valley north and northwest of Bristol, Virginia. The estimated limestone value of the Chester group of formations in southwestern Virginia is fully corroborated by correlation of the successive beds with those in the section of Monte Sana near Huntsville, Alabama. That the estimate probably falls short of the truth is indicated by the presence of considerable beds in the Appalachian Valley that are absent in Monte Sana, western Kentucky, and southern Illinois.

The estimated thickness of the Pennsylvanian is taken from published accounts of sections in Nevada, New Mexico, and western Texas, where much the greater part of this system is represented by limestone deposits.

Suggestions concerning Nomenclature of stratigraphic Units

GENERAL DISCUSSION

Effect on nomenclature of shifting or modification of boundaries of stratigraphic units.—With any considerable shifting or modification of the boundaries of stratigraphic units the matter of nomenclature becomes a serious problem. For instance, if in the revision of a system it loses certain beds at either its top or bottom or from both extremities: shall we continue to apply the same name to the residium or should it be christened anew? So long as it retains the main and most characteristic part of the system as it was originally defined, or, in some instances, as it became generally known, it seems to me desirable to retain the old name. The revised Silurian, from which the greater part of the old "Lower Helderberg group" is removed and to the base of which it is now proposed to add the Richmond—changes that do not materially alter the prevailing conception of the system—illustrates these cases. Rather more difficult are those instances, like the Ordovician, in which the generally accepted estimate is cut into two almost equal parts. But even in this case, may not the desire to preserve the old name justify its restricted application to the more typical part of the divided system? Unquestionably, the Glenkiln and Hartfell shales and the Bala, in Great Britain, and the beds between the base of the Chazy and the top of the Maysville group, in America, are more characteristically associated in the minds of geologists with Murchison's Lower Silurian, or with its substitute Ordo-

vician, than are the much less understood older formations which recent studies have shown to be equally important in their physical and organic histories and therefore worthy of being classed in systems of their own.

In my judgment it would be of distinct advantage if the boundaries of stratigraphic divisions comprising two or more formational units were elastic. Indeed, the advantage of elasticity is apparent even in the case of many of the formational units. In recognizing stratigraphic divisions the rule in the past ten or fifteen years has been to adhere strictly to the original definition with particular reference to the type section. In its essence this rule is unquestionably a good one, but its strict enforcement often leads to unnecessary duplication of names and to difficulties in the exact determination and the graphic expression of correlations.

Many of the formations, and in recent years most of the larger ones, have been established without sufficient regard to subsequent necessary correlations with some well established standard. Often because of difficulties in cartographic representation, or it may be for no other reason than lack of time for detailed work, formational units have been so broadly drawn that they include one or more important and sometimes easily discriminated natural boundaries. Besides obscuring or ignoring the full history of the beds, it is an unnecessary burdening of stratigraphic nomenclature to apply definite names to such arbitrary divisions of the stratigraphic column. In subsequent exact and detailed stratigraphic work these names must be either dropped into the limbo of the useless or be redefined and restricted to some natural part of the mass originally included under it. Obviously there are weighty objections to the latter disposition of such names. But considering the difficulties frequently attending the selections of suitable names, also the fact that usually the later more detailed and presumably improved account practically relegates the now inadequate original work to the "scrap heap," it may well be questioned if the generally but slight confusion incident to such restriction should be regarded as prohibitory. To insure exact understanding it is suggested that subsequent usage of a redefined term should be accompanied by the name of the authority for the particular meaning intended.

It seems to me that stratigraphic terms, especially those of a higher rank than formations, might well be regarded as subject to modifications similar to those allowed in the definition of zoological names. In defining a genus, which may be compared with a system or group, the first essential is the selection of a genotype—theoretically the species affording the best expression of the generic characters. All species regarded as more nearly related to this typical species than to any other generic type then

recognized are associated with the selected genotype, the resulting group of species constituting the author's conception of the genus. Subsequently other species found to possess the generic characters are added. In other cases the species originally or subsequently associated into a single genus may be found to embrace two or more groups of species sufficiently distinct to be ranked as separate genera. In the revision the old name is retained for the group containing the original genotype, other generic names, either new or previously established, being used for the eliminated groups. In stratigraphic classification a similar selection of a type—in this case an especially characteristic or persistent bed or faunal association, or some definite period of time—would be of manifest advantage to subsequent investigators. The practical application of such principles seems clear enough to render examples unnecessary. Suffice it to say that progressive reconstruction would be possible without totally wrecking previous nomenclature. And the time is near when some definite method of revising or of disposing of the numerous local stratigraphic designations will be demanded by the advance of detailed correlations.

Concerning overlapping formations.—Speaking of formations, one very common difficulty is to decide to what extent an overlapping formation may be reduced in thickness before another designation is desirable? In the case of a formation that is justly described as an indivisible stratigraphic or lithologic unit—meaning that it does not include a measureable stratigraphic hiatus—all will probably agree that the same name is properly applicable from the locality of maximum development to its vanishing edge. But when the formation is not strictly a unit and it is found to comprise two or more lithologically distinguishable members, or one or more stratigraphic hiatuses, or when the lithic characters of the whole or of some part of the formation change laterally, then opinions are likely to differ in deciding the nomenclature of extensions of beds falling within the limits of the formation in question. If it is a simple case of overlap of a formation consisting of two or more members, none or only the lower of which has been given a subordinate name, the same name should be used so long as any part of the lower member is recognizable in the section. Beyond the point of its extinction a new name, providing beds corresponding to the remaining member or members have not received a formal designation elsewhere, is commonly advisable. Should the formation be one of three members its reduction by overlap to the last makes a third name desirable; but only when the middle and upper members are united under the second name at the intermediate locality. Should all of the three members, or both of the upper two, or only the last,

have been separately designated the giving of a new name at the third locally would be unnecessary. When two or more of the members have thus become separately recognized the original formation name takes on the rank of a group term, while the members become formations on the ground of being either lithologic units or stratigraphic units separated by physical and faunal criteria indicating interruptions of the process of deposition. A great variety of conditions depending on overlap of deposits, irregularities in distribution, erosion of upper members, lateral change in character of sediments, etc., and each requiring some corresponding modification of the rules of nomenclature may be imagined and indeed are encountered in daily practice. The really very rare condition of a tangential basal deposit thick enough to be worthy of a separate name will be discussed later on.

Local stratigraphic terms.—No local section contains within itself the data required for anything approaching a final classification of its component parts. This becomes possible only when exhaustive comparisons with many other near and far sections have been made. It is for this reason chiefly that the indiscriminate and irresponsible naming of lithological units is objectionable. The divisions are seldom drawn with due regard to the organic and diastrophic histories of the several beds. The practice is defensible only on the ground of expediency, but it is a question if the good gained through it ever balances the evil done to the science as a whole. Still, I am willing to admit that hitherto it has been a necessary evil; but is it so today? The evil, too, would be much less if the suggestion on a preceding page concerning elasticity of boundaries were adopted. Many of these local names, originally perhaps given in ignorance, may with slight emendation be made to serve a good purpose.

I should not be misunderstood as saying that the need for new names has been satisfied. On the contrary, a great many more are required to properly classify the stratigraphic units already known. I do not therefore wish to discourage the naming of formations that have been proved to differ in one or another valid respect from all related formations; but I do object to names proposed solely because of admitted ignorance respecting the relations of the beds in hand to some standardized section. This knowledge should be acquired before the new section is classified and supplied with a nomenclature; or if it is necessary to publish before this can be done purely temporary designations will serve the purpose of the author quite as well as a new set of formal names. There can be no valid excuse for a "formation" name like the "Shenandoah limestone;" nor is there a sufficient reason for applying two distinct sets of names for the Paleozoic formations in the Black Hills and the Big Horn Mountains,

or for a new set of names in Indiana when those used in Illinois and Kentucky are clearly applicable. Good names for new formations are too scarce to permit such waste of material.

THE STANDARD SECTION FOR AMERICA

That no single region of the size of a State contains within its borders sufficient data to work out a complete marine sedimentary record of even a single geological period, much less of an entire era, is suggested by the course of stratigraphic studies in New York. This State has been active in geological matters for upwards of three-quarters of a century, and more than any other in America has furnished the data upon which the present pre-Waverlyan standard section is based. Although the essential features of the New York section were believed to have been completely worked out more than sixty years ago, it is nevertheless a fact that as a result of more modern methods of research the aggregate thickness of this section has been more than doubled in the past twenty-five years. This was accomplished, not only by finding that the maximum thickness of some of the formations is greater than had been thought, but, perhaps to an equal or greater extent, by discovery of facts proving that great deposits in eastern New York are not, as had been assumed previously, equivalent in age to beds in the central and western parts of the State, but are really either younger or older and in whole or part new elements of the geological column. And the end is not in sight. Even the best known sections are under suspicion and are being revisited by geologists of the State and Federal surveys in the hope that some hitherto overlooked feature may be discovered.

More disturbing than all this is the gradually growing fact that the pre-Devonian part of the New York section is far less complete than had been supposed. Except at a few localities to the east of Hudson River the State contains no true Cambrian rocks; and even these exceptions offer but an insignificant representation of this great system. The lower middle part of the Ozarkian is fairly well developed on the south, east, and west slopes of the Adirondack uplift, but for the higher and basal parts we must go to Missouri and the southern Appalachian region. As for the Canadian system northeastern New York offers both the shale and limestone phase in sufficient development to rival central Pennsylvania—where the deposits are thicker but less fossiliferous—in supplying data on which the standard for America is to be based. Our conception of the Ordovician, Silurian, and Devonian systems in America is so long and firmly grounded in the New York section that any attempt to introduce another standard is likely to prove futile. Still it is necessary to go

elsewhere for certain important parts of the sedimentary record that happen to be either wanting or not well shown in New York.

In accepting the New York section as the standard for especially the Ordovician, Silurian, and Devonian systems in southeastern North America, it seems to me we should endeavor to apply the New York nomenclature as far as a liberal interpretation of the facts will permit. Of course we should not go back to the practice of our fathers who required but one set of formation names which they applied with great confidence in all parts of the country. Today we realize that only a few of the names given to lithologic units in New York are strictly applicable to stratigraphic units recognized in the Ohio and Mississippi valleys. The Lowville and Onondaga limestones are the best and perhaps only unquestionable examples, but with some shifting of boundaries a few others would pass. Yet other formations are quite as typically developed in the Appalachian Valley as in New York, and in these cases it would be a pity if the New York names were not extended southwardly in designating the corresponding beds, whether they are viewed as distinct formations or as members of the larger formational units commonly thought unavoidable in mapping the rocks of folded areas.

Correlations being established and the lithic characters reasonably uniform, the remaining essential condition on which the applicability of a New York formational designation in other than the typical area is determined is that the deposits should belong to the same continental sea. In other words, when the faunas and waters which laid down a New York formation can be traced to the Gulf of Mexico in one case, the north middle Atlantic in another, or possibly the Arctic in a third, the deposits of similar age and character in the path of the particular invasion should be known by the same name. This rule implies continuity of such formational units and it is doubtless so even when the fact can not be demonstrated by uninterrupted outcrop. Oscillatory movements and consequent irregularities in shifting of strandlines of continental seas were too frequent to render such continuity of crop at all common.

Many of the stratigraphic units, more particularly of the Ordovician and the upper series of the Silurian, are represented in New York by not only a lesser thickness of deposits, but the accessible marine record there indicates more frequent and longer enduring interruptions of the process of sedimentation than in areas to the south. This is explained by the fact that each of these formations represents a distinct invasion of the sea and that the ensuing deposits overlap to extinction on the sloping surfaces of contemporaneous land projections extending into northeastern New York from Canada. In consequence the eroded edges

of these formations, which are found in most instances still well up on the flanks of the old lands, commonly do not include a depositional record of certain earlier stages of the several transgressions that are well represented in the thicker sections of central and southern Pennsylvania. Indeed, some of the invasions from the south failed entirely to reach the probable line of outcrop in New York. An instance of such failure is the post-Lowville part of the Chambersburg limestone, a composite formation that is rather fully described on pages 321 to 329. As defined and mapped by Stose, the Chambersburg comprises three well distinguished members, all of them older than the base of the Trenton. The middle division seems unquestionably a representative of the Lowville, and following it there is an abrupt and complete change in faunas. The upper member attains a maximum thickness of over 600 feet and has every attribute of a distinct formation, with a time value quite equal to that of the Trenton. Perhaps small parts of its time are represented in the New York section by the recently named Watertown and Amsterdam limestones, but considered as a stratigraphic unit, this important upper member of the Chambersburg certainly failed to reach New York. In fact, the head of the narrow bay in which it was deposited did not extend north of Harrisburg, Pennsylvania.

We have already discussed the question, how much reduction is permissible in an overlapping formation before another designation is desirable? The preceding paragraph presents the opposite condition of expansion. In my opinion, the only practical solution of this phase of the question is to continue adding to the bottom of the stratigraphic unit, be it of the rank of a member, a formation, or a group, until we encounter beds clearly referable to the next underlying equal unit of the standard section or some other well defined boundary. In the latter event the expanded section may contain a new formation or other stratigraphic unit that henceforth becomes an integral part of the geological scale.

BROAD INTERPRETATION RECOMMENDED FOR OLD NEW YORK TERMS

As a rule, it seems desirable to give as broad an interpretation as possible to the formation names finally adopted by the geologists of the first New York Survey. They were used so widely by the older geologists, and withal so loosely, even in New York, that their original significance has in some cases become obsolete. It is from these chiefly that the stage or group and epoch or series names should be selected. In their revision of the New York section Clarke and Schuchert, in 1899 and 1903, the latter a slightly amended edition published by Clarke alone,

much good was accomplished in the way of coordinating the different grades of units and in bringing the standard into harmony with the progress of knowledge not only in New York but also to some extent with stratigraphic facts acquired elsewhere in America. In viewing the result it is to be noted that some of the old terms (Mohawk, Oswego, and Niagara) have been raised to the rank of series, and one (Oriskany) to that of a group. In two cases, however (Helderberg and Erie)—in both for valid reasons—the original meaning is greatly restricted. It is not my present purpose to discuss the merits of this revised classification, except to say that enough has been learned in the past ten years, particularly concerning the pre-Devonian part of the scale, to make another revision highly desirable. New terms of all ranks must be intercalated, and those in the "age or stage" column require discrimination by promotion of some of the terms to the group column.

Reverting to the perpetuation of old New York terms in some reasonable approximation to the wide sense in which they were employed by former generations of geologists, I shall briefly refer to those in which my personal interests are chiefly concerned. Beginning below and going up in the section, the first is the Chazy. This term was applied by Emmons to a series of limestones in the Champlain Valley that we now know to be not only much thicker than Emmons thought but it is also divisible into three formations. Moreover, on comparison with middle and southern Appalachian sections, it is found that in the Champlain Valley the boundary between the middle and upper formations represents an important hiatus and that the interval between the top of the upper and the base of the lower formation attains aggregates in historical and time values entitling it to the rank of a series or epoch. It is with this significance and in the form of Chazyan that I propose henceforth to use this name.

The second of these terms is the Black River. As originally defined this term included all the beds in the Black River Valley between the base of the Lowville ("Birdseye") and the base of the Trenton. Later Hall confined it to the "7-foot tier" at Watertown, New York, but in general practice he and most other geologists applied the term to all beds between the Lowville and the Trenton. Recently it was decided in conference with the geologists of the New York Survey that inasmuch as a group term is desirable the least confusion would be occasioned by revival of the term in its original significance. In this sense, then, it is proposed to extend the application of the name Black River from New York westwardly to the Mississippi Valley and southwardly to exposures of similar rocks in the Appalachian Valley.

The Trenton is the third name that is to be used with a definite stratigraphic value beyond the confines of New York and Ontario. In most areas it is readily divisible into members or distinct formations, and its time value is about the same as that of the Black River group. In the scheme of classification that has been prepared for Part III of this work, both of these terms are given the rank of groups; but this technical rank does not preclude the use of the names in the formational sense, especially in areas where it is inexpedient to distinguish thin stratigraphic units. Together the two groups constitute the Mohawkian series.

The Clinton finally is another of the old terms ranking with the Black River and Trenton that is to be used in a similar manner. It being now conceded that the Rochester shale zone is included in and forms the top division of the typical Clinton, and as the part beneath the Rochester is locally divisible into several lithologically and faunally distinct members or formations, the composite Clinton unit manifestly has become a group. It is so regarded in my proposed classification, in which it constitutes the lower of two groups into which the Niagaran series is divided. However, on grounds of expediency and convenience in mapping, and because in its eastern development the subdivisions are, as a rule, not easily distinguished, the Clinton is viewed as a single stratigraphic unit in the long belt extending southward in the Appalachian Valley from Clinton, New York, to central Alabama.

RELATION OF FORMATION NAMES TO TIME TERMS

Following the recommendation of the International Congress of Geologists, geological time is generally classified into *eras*, *periods*, *epochs*, *stages*, and *ages*. The stratigraphic units are similarly arranged into *systems*, *series*, *groups*, and *formations*, four classes theoretically corresponding to those of the time scale below the rank of eras. But in general practice the stratigraphic units termed "formations" often bear no definite relations to the time units of the grade of "ages." In fact, the units of the lowest and next higher ranks in either scale are often far from coordinate. This is unavoidable and remediable only with time, being due to unequal exploitation of different parts of the stratigraphic column. But can we not do something now to improve matters? Must all the units of a given map be treated as though coordinate, even if one includes thick beds referable to two or more periods and another is but a simple lithologic unit of relatively insignificant time value? Why not call one the Clinton group, another the Helderbergian series? Such qualifications would immediately convey desirable information and indicate that these formations are taxonomically more important than is the Tusca-

rora sandstone. And would it not have been better to refer to the "Valley limestones" as *undifferentiated Cambrian and Ordovician formations,* instead of by the unclassifiable and hereafter quite useless name "Shenandoah limestone"? Or, to cite another case in which several distinct lithological units of very different ages, and thought to be too thin to be separately delineated, were arbitrarily associated under the name "Panola formation," would it not have been better to speak of this strip of the map as covering *undifferentiated Silurian and Devonian formations?* Or, better still, if time had been taken to determine and define the several stratigraphic units, as has since been done by Foerste,[32] they might have been properly named and described in the text, though remaining wholly or partly undifferentiated on the map? Doubtless the science of stratigraphy would benefit greatly if the formational units were determined by the criteria and principles of the science rather than by cartographic limitations and the time available for field studies.

Regarding the use of terms in two distinct senses, as, for instance, Trenton limestone, meaning a formational unit of definite lithologic characteristics and limited geographic extent, and Trentonian, referring to a much broader time interval than that represented in the Trenton limestone proper, I am unalterably opposed to it. Happily, the practice is being rather generally discouraged, so that we may confidently look forward to its entire and early abrogation. The use of the suffix *an* or *ian,* which is commonly used to distinguish the term when employed in a time sense, should never imply either more or less than a time space corresponding in duration to that required to lay down the rocks known by the simpler form of the term. Any departure from this rule leads to confusion. As a rule, it seems to me we might get along very well without using the suffix at all, except as applied to terms of the rank of series or epochs. It may be more euphonious to say Trentonian time or Trentonian age than Trenton time or Trenton age, but it is neither more exact nor more easily understood.

Finally there are occasions when in writing a term some obvious distinction between the two senses in which it may be applied would be advantageous. Such occasions, however, need arise only when dealing with names of formations used also in the time scale. It has been suggested—and the plan seems a good one—to italicize the word when it refers to the age and not to the lithologic unit itself. Other contingencies suggest a similar mode of discrimination. Thus we may wish to speak of some local lithological phase or part of a stage or series, as, for

[32] A. F. Foerste: Kentucky Geol. Survey, Bull. No. 7, 1906.

instance, the Bigby *Trenton* or the Maquoketa *Richmondian*, the minor term being given the qualities of an adjective. Or it may be desirable to refer to the time of the Bigby, which term, having perhaps not yet attained general recognition, exactitude of expression might be secured by writing *Bigby Trenton*. Finally, in discussing thick formations in which one or more ages is recognized, these ages or parts might be referred to as the *Trenton* Chickamauga, the *Lowville* Chambersburg, the *Pamelia* Stones River, the *Rochester* Clinton, the *Onondaga* Romney, etcetera. Often, too, one may insure exact and immediate understanding of time significance of local terms by using an expression like "the middle Trenton Bigby limestone."

PART II. CRITERIA AND PRINCIPLES OF STRATIGRAPHIC CLASSIFICATION

Diastrophic Criteria

BODY DEFORMATION CAUSING VERTICAL MOVEMENT OF LAND AND SHIFTING OF CONTINENTAL SEAS

General discussion and permanence of oceanic basins.—An adequate discussion of the criteria and principles of diastrophic correlation would fill a volume—and doubtless the effort would be worth while. But on account of lack of space summary treatment, confined as much as possible to the practical aspects of the main purpose of this work, must suffice for the present. It is to be said, however, that much of the matter to be presented under the heads "gradational and lithological criteria" (pages 467 to 480) and "correlation by lithological similarity" (pages 519 to 532), also in several chapters of Part I, is really a discussion and application of diastrophic criteria. Even the organic criteria are, to a large extent, expressions of diastrophic activity.

For purposes of stratigraphic correlation and classification the primary cause or causes of diastrophic movements—especially those resulting in considerable horizontal shortening—are not of vital importance. We are here concerned chiefly with the fact that such movements have taken place and with the determination of the general nature of their effects on agencies at work on the surface of the earth. It will be agreed by most of us that such deformation had a fundamental bearing on the migration of the strandline and on the relative elevation or depression of parts of the surface, hence on the extent of marine deposition and the character of the deposits. It also affected the evolution and distribution of faunas.

Chamberlin's views.—Two widely different conceptions of body deformation prevail among modern geologists. The important features of these divergent views have been briefly stated by Chamberlin in a paper entitled "Diastrophism as the ultimate basis of correlation."[33] As I concur in general with the principles advocated therein by this authority, a few sentences quoted from this paper will serve present purposes perhaps better than any I might write. He says: "There remain two conceptions of general or body deformation between which choice must be made. In the one, the deformations are supposed to be indifferent to their predecessors and to disregard the configurations produced by previous deformations. Their successive effects upon continental outlines and basin capacities are thus heterogeneous and the combined results irregular and uncertain. . . . The submergent phase of one continent or fraction of a continent may, in this case, be contemporaneous with the emergent phase of another continent or fraction of a continent, and the progress of events on one continent is as likely to be contrasted with those of another continent as to fall in with them coordinately." This conception, entertained chiefly by certain European geologists, is rejected by Chamberlin on what, especially as regards the indifference of deformations to their predecessors, seem to me valid grounds. The last of the quoted sentences seems less objectionable, since, as explained on pages 405 to 409, the conditions mentioned are probable also under the second conception.

"According to the other view, deformations are inheritances, one of which follows another in due dynamical kinship. The succession is therefore homogeneous and the results coordinate. If, for example, the first depression of the abysmal basins was due to the superior specific gravity of the basin-bottoms, this specific gravity remained and participated in the next deformation. If the continental masses, at the outset of continental formation, were relatively low in specific gravity, this low specific gravity was handed down to later periods and helped to renew deformation of the same phases in the same regions. Under this view, ocean basins and continental elevations tended toward self-perpetuation. It is not assumed that this prevented shell crumplings, provincial warpings, or block movements of diverse phases within the continental or the abysmal areas, for these might obviously be necessary effects of the general deformative movements, or at least inevitable incidents connected with the dynamics lying back of them. . . . Each great diastrophic movement tended toward the rejuvenation of the continents and toward the firmer establishment of the great basins. . . . The baseleveling processes have

[33] T. C. Chamberlin: Journal of Geology, vol. xvii, 1909, pp. 685-693.

shown that they are able to lower the continents approximately to the sea-level in a fraction of geologic time. The continents would therefore have long since disappeared, if they had not been rejuvenated by renewed relative elevation or the withdrawal of the sea. . . . There are some submerged dependencies and intercontinental connections. . . . In the earlier eras, when the differentiation of platforms and basins was less advanced, ridges which have since been submerged are perhaps recognizable. . . . In the earliest known ages, these may have been rather numerous and their combined area considerable, but these seem to me to be only qualifying features which, by the natural place in evolution which they fill, support, rather than weaken, the general conception of a symtematic succession of deformations in which the offspring of each is parent of the next, and in which both continents and ocean basins were progressively segregated and unified."

The latter of these two conceptions is held rather generally by American geologists. The results of my own investigations tend to show that it holds true not only for the continents and oceanic basins on the whole but also for relatively small portions of each continent. Once started, the areas of relative uplift have always continued to be areas of stratigraphic overlap or of land, while the relatively depressed areas remained as a rule areas liable to subsequent submergence. Though the surface of the lithosphere was affected by innumerable minor differential vertical and horizontal movements and the strandline is forever changing, the continents and the oceanic basins yet permanently retained essentially similar geographic relations to each other. The truth of this conception, especially in so far as it concerns continental areas of elevation and depression, is abundantly attested by detailed studies of the formations in and around areas of Eopaleozoic rocks. Some evidence of this kind may be gleaned from the introductory chapters, and more from following pages describing vertical movements of median continental areas and corresponding oscillations of continental seas, while considerable additional information respecting localities of repeated overlaps is in hand and ready for publication through other channels.

Willis's views on permanence of oceanic basins.—Chamberlin (op. cit., page 688) in saying that "there are some submerged dependencies and intercontinental connections," takes a broad and liberal stand respecting the probable former existence of considerable landmasses in areas now covered by the great oceans. Willis,[34] however, though he does not com-

[34] Bailey Willis: "Principles of Paleogeography." Science, vol. xxxi, No. 790, 1910, pp. 243-246.

mit himself positively, still seems to question the possibility of a Gondwana land, and of transatlantic lands, one connecting South America and Africa and another North America with northern Europe. That such dependencies and intercontinental connections did exist at various times in geologic history—their exact location is another matter—seems incontrovertibly established by the geographic distribution of certain fossil faunas and floras. These east-west connecting lands were emerged at times when the horizontal movements of the shell in a north-south direction dominated those acting in the opposite direction. The latter won in the long run, the connecting lands being finally dragged down in the aggregate growth of the oceanic geosynclines to depths from which it seems unlikely that they can ever again emerge.

I must take issue with Willis also when he says (Science, February 18, 1910, page 243) "in their genesis ocean basins and geosynclines may have been similar; but in their dimensions, histories and structural relations they are *radically* different;" and again to his succeeding statement (op. cit., page 244) that the "distinction between geosynclines and ocean basins is fundamental" because the former "occupy positions among the positive continental elements" the latter "separate and surround continents . . . and no ocean basin has been compressed, crumpled and raised, after the manner of the Appalachians or Alps." As I see it, the differences are merely relative—matters chiefly of magnitude—and therefore neither radical nor fundamental. Indeed, in conceding similarity in genesis, Willis himself tacitly admits this. Had he compared a whole continent and not merely one of its compound synclines with the oceanic basins, he might perhaps justly have called one the antithesis of the other, the one being characterized by dominance of positive tendencies, the other by negative. Both, however, include areas that are synclinal in structure, being relatively depressed, with respect to adjacent areas, and each of the oceanic basins comprises several pronounced geosynclines and weaker geanticlines just as the continents are made up of several strong geanticlines and relatively subordinate geosynclines. That compression and resulting folding and crumpling was developed to a less degree in the irregular floor of the oceans than on the continents is probably true, but to say that no ocean basin was compressed "after the manner of the Appalachians" seems unreasonable. That there is no sharp boundary of fundamental structural significance between those parts of the earth-crust that lie beneath the sea and those which form the land is shown, as I believe, conclusively by the fact that compressed and folded areas, both new and old, still high or reduced, strike from the land into the sea. And the contours of the

ocean bottoms surely indicate great diversity in the way of broad and deep valleys and undissected ridges. These submarine ridges naturally receive less deposit than the valleys, and they are belts of relative weakness for much the same reasons that have made the similar ridges of the lands less resistant than the heavily loaded downwarps. Why, then, should they not have been at times compressed and raised in the "manner" of the Appalachians? Further, as each geosyncline is essentially a compound syncline, so each again is included in a still broader structure that might be called a compound geosyncline. Under this view the differences in dimensions and structure are less formidable. So far as I can see, the whole difference, then, is limited to variations in degree of development and to the circumstance that on the one hand we are dealing with land expressions of the originating process and on the other with its development under water.

Periodicity of movements—General discussion.—The statement previously made that "the strandline is forever changing" does not imply that diastrophic movements have been in constant progress in any given era. Adjustment of minor and local stresses, which may be preliminary to or follow stronger movements, and the slowly transmitted diminishing effects of oceanic thrusts, doubtless occurred in one or another place almost constantly. But there were other, more consequential deformations, that must have taken place periodically. These were movements in a horizontal direction, accompanied by warping, folding, and overthrusting, whose major effects, following the Proterozoic, were confined to the marginal areas of the continents. Though probably slow and long continued in their progress, the times of their prevalence would seem to have been rhythmically periodic. That these movements recurred at intervals separated by times of relative quiescence is in accord with theoretic considerations and proved by the fact that baseleveling, which involves as a prerequisite a considerable stability of surface, can be shown to have occurred during the later submergent stages of most of the periods. Considering the exceeding shallowness of the continental seas, especially of those most concerned in the inquiry, the great extent and rapid advance of these submergences would have been impossible except under conditions of approximate baselevel.

That the movements were rhythmic in time of occurrence and kind is strongly suggested by the approximate coordinateness of the successive systems as measured by their respective limestone values (see page 381). The average thickness of accessible deposits (reduced to a limestone basis) for the eight Eopaleozoic and Neopaleozoic systems is not far from

5,000 feet. Those exceeding this amount (Cambrian and Devonian) are thought to comprise more of the sedimentary record in accessible situations than usual, while those of which the known amount falls considerably beneath the average suggest longer intersystemic and intrasystemic intervals of inaccessible depositional records. This suggested explanation of the difference in the known aggregate thickness of the respective systems is based on the wide extent of the Warsaw, or first Tennessean invasion, and the similarly wide extent of the Pottsville transgression, implying in both cases a preceding long period of baseleveling, and it finds support in the well marked differentiation sustained by the southern Atlantic fauna in the time between the Keokuk and the Warsaw and again between the last of the Chester and the first of the Pottsville. In both instances the change is greater than between the latest Devonian and the early Waverlyan facies of the same fauna. Great caution, however, is required in making such faunal comparisons, they being truly significant only when the successive facies are derived from the same oceanic basin.

In my opinion a rhythmic relationship connects nearly all diastrophic movements. For a few the meter is very long, for others shorter, and for still others much shorter. The last may be arranged into cycles and these again into grand cycles, the whole arrangement probably corresponding in units to the divisions of an ideal classification of stratified rocks and, so far as these go, of geologic time. The determination of the relative importance of diastrophic phenomena is of course exceedingly difficult. At present their classification is fraught with uncertainties, whose elimination offers a never-ending task to present and future generations of geologists. Although prevailing interpretations vary greatly and progress is much impeded by inherited erroneous opinions, we may yet claim that enough has been established to give a reasonable generalized conception of the order of geologic events. And as to the broader relations of the minor occurrences, these, too, in many instances, are beginning to be understood and used in correlation. As I shall endeavor to show in succeeding parts of the present work and on future occasions, diastrophism affords a true basis for intercontinental correlation of not only the grander cycles but also of their subordinate stages. As yet I am unwilling to acknowledge any limit to the possibilities of stratigraphic correlation. The principle of rhythmic periodicity being recognized, it seems to me merely a matter of time and close comparative study of sedimentary records and faunal associations to determine the time relations of interruptions in sedimentation in any one section to similar interruptions in another.

Willis's views on periodicity of diastrophism.—Willis[35] recently published a brief statement of his views on the periodicity of geologic events and processes. He recognizes the principle, but qualifies it by grouping the phenomena of diastrophism according to several distinct dynamic regions, each of which he supposes to have had its individual history, "expressed in cycles of movement and quiescence peculiar to itself." "The cycles of one region have been, however, to some extent parallel, though not coterminous, with the cycles of other regions, and thus major cycles of world-wide conditions are constituted by coincidence of regional conditions." This qualification is based on the belief that the diastrophic history of the lands adjacent to the north Atlantic differs in essential particulars from that of the lands bordering the Arctic and Pacific oceans. He says that the "lands about the Arctic Ocean did not share in the Atlantic movements of Silurian, Devonian, and late Paleozoic epochs;" that "in the Atlantic provinces the Paleozoic era closed with marked diastrophism, while comparative tranquillity reigned around the Pacific," and that "the Pacific provinces were greatly disturbed in the middle Mesozoic when quiet had supervened about the Atlantic."

On the face of the accessible sedimentary record in the respective regions these allegations may seem well founded. But even the visible part of the evidence is not altogether in favor of the quoted statements. Neither are we justified in claiming, because abundant clastic deposits and other indications of active diastrophism are preserved in one area and little or nothing of the kind is found in another at approximately the same age of the geologic time scale, that the two areas did not share in the same deformative movements. The share in the one case may have been small, in the other large. In fact, no two areas, however near, participated in exactly the same way or to exactly the same degree in the movements of any period. The more conspicuous phenomena induced by body deformation of the earth, such as mountain making, are merely local effects of the movement as a whole. While the positive areas were elevated, immediately adjacent negative areas were relatively depressed; and more distant regions may have shared in the movement only to the extent of either gentle subsidence or perhaps slight emergence. Whether it built mountains in one place and caused but gentle warpings in another, or whether the mountains bordering one oceanic basin are contemporaneous with a similarly located slight elevation in another, or even a subsidence in a third, they are all only different manifestations of the same period of diastrophism.

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[35] Bailey Willis: "Principles of Paleogeography." Science, vol. xxxi, No. 790, Feb. 18, 1910, pp. 246-249.

That the lands about the Arctic Ocean have not been folded like those bordering the Atlantic and Pacific oceans and those flanking the east-west Gulf of Mexico and Mediterranean depressions, of course implies decided differences in diastrophic history. Evidently, tensional stresses, with crustal flow toward the equator, predominated in the circumpolar regions, while compression, resulting in part from equatorial flow of lands and seas, and in part from suboceanic spreading acting from the water side and continental creep from the other, prevailed as a rule in the folded tracts. But these differences in history are not prohibitive to exact correlation of geologic events transpiring in the several regions. It is highly improbable that mountain making took place at any one time on all the continents; and it is certainly not true that the folding observed in any mountainous tract dates all from a single period of diastrophism. To postulate a period of major diastrophic activity, we need but to establish that strong folding actually occurred at such time in certain regions, and this proof should be sufficient warrant for the beginning of a new geologic period. What occurred elsewhere at about the same time becomes merely a matter of interesting detail—doubtless important in so far as it shows the extent and relative taxonomic importance of the deformative movements. However, this detailed information is very desirable and to a large extent essential to properly define and discriminate the respective periods in regions of varying dynamic history.

And is the evidence wholly satisfactory on which is based the postulate of marked diastrophism in the Atlantic provinces at the close of the Paleozoic and comparative tranquillity around the Pacific at the same time? Or for the supposition that quiet had supervened about the Atlantic in the middle Mesozoic when the Pacific provinces were greatly disturbed? Since the areas in which decided folding occurred are largely confined to the marginal parts of the continents, may it not be possible that tracts bearing the physical record of important diastrophic movements are now submerged or buried beneath more recent undisturbed sediments? Finally, is the evidence on which it is inferred that the folding of the Appalachian Valley was accomplished and marks the close of the Paleozoic quite incontrovertible? As will appear from later statements (see pages 468 to 477), I think not.

Displacement of strandline chiefly relied on in proving periodicity of deformative movements.—The only thing that moves apparently in the same way and degree, and which, therefore, offers the most reliable criteria in determining the periodicity and contemporaneity of diastrophic

events, is the level of the sea. Even this statement must be qualified, since, under the perhaps well grounded conception of a periodic equatorial heaping of the waters, the level of the several oceans may rise or fall in the same measure only at the same latitude, and then only when the proportionate bulk and altitude of adjacent land-masses remains unchanged. But, whatever the qualifications, there yet remains the fact that the strandline is contemporaneously and universally displaced. Obviously the exact correlation of these displacements at times of great and diversely manifested diastrophism, as at the close of periods and eras, is more difficult than are the more eustatic migrations of the strandline which occurred at intervals within the durance of the periods. Doubtless the times of excessive crustal deformation are everywhere indicated by some marked change or break in sedimentation; but the break is likely to be a long one and the determination of its time relations in two or more areas correspondingly indefinite. During parts of the interval represented by a well defined intersystemic hiatus deposition may have been going on elsewhere; and it is sometimes very difficult to decide whether these intervening deposits represent later stages of the old period or earlier beds of the new or, as often happens, of both. In the last event several perhaps equally distinct boundaries may occur within the intervening mass, and as all the criteria relied on in distinguishing the two systems in the first case are more or less weakened through transition, it may indeed become a matter of no small difficulty to decide which of the boundaries is the most important. The Siluro-Devonian boundary in southeastern North America and in central Europe affords a good illustration.

The displacements of lesser rank, such as define series and groups, are more readily amenable to intercontinental correlation. It is not that the deposits of a given epoch can be more easily recognized in the several continents than those of the much larger period unit, but that the average time value of the breaks is less and the competent accessible data more numerous, thus enabling us to reduce the limit of error in determining the equivalence of intrasystemic boundaries to less formidable dimensions than when we seek to correlate the terminal deposits of a system. For instance, it will be less difficult to establish the exact time relations of the subdivisions of our Niagaran series to the Silurian zones recognized in England and Sweden by diastrophic criteria—using that term in its broadest sense—than it will be to prove that the Manlius of New York is not represented in the upper part of the Wenlock, or that the Ludlow group—yes, even the Dudley limestone of England—does not include beds of the age of the Helderbergian in America.

It is not my intention to imply that the systemic boundaries can not be drawn in the several continents so as to insure against the possibility of referring contemporaneous beds to the top of, say, the Silurian in Europe, and to the base of the Devonian system in America. On the contrary, I believe that accuracy in correlation, whether narrow or intercontinental in scope, depends solely on the uniform application of the criteria and principles adopted, and that if our practice is thoroughly consistent we shall finally succeed in discovering physical boundaries that will separate the systems so that none will include beds of ages elsewhere referred to either the preceding or the succeeding period. This may sound unduly optimistic, but judging from my own experience in the still young science of stratigraphy it is not so. The greatest difficulties lay not in the correlation of sections personally studied; they arose rather from the continual expansion of the stratigraphic column and the frequent readjustments and changes in classification thereby necessitated. In short, they have been taxonomic rather than objective; and withal never so great as to discourage the hope that where I have failed others may succeed.

Results of recent methods of correlation.—The feature of advancing knowledge of stratigraphic correlation that more than any other is responsible for the expansions of the sedimentary record briefly outlined on pages 379 to 381 lies in the gradual conviction that instead of stable, slowly growing continents covered with great, long enduring and deep interior seas, the surface of the continents was exceedingly unstable and subject to frequent oscillation and more or less local warping, the seas were correspondingly inconstant, shallow, relatively small, and frequently withdrawn entirely, only to reappear in forms simulating preceding geographic patterns. The effect of this revised conception seems so far-reaching that if proved true it must greatly modify—perhaps revolutionize—stratigraphic geology. Possibly this statement is stronger than is warranted by the evidence. But the facts bearing it out are not only abundant and of varied kinds, but they are repeated over and over again so much that I can not help being convinced of the truth of the principle of oscillating seas and lands. In fact, this principle is at the basis of whatever new philosophy is established or suggested in this paper.

Not so many years ago it was commonly accepted that extensive migrations of the shoreline resulted principally from *en masse* elevation and subsidence of the continents. Latterly, and more particularly since the publication of Suess's "Antlitz der Erde," the transgressions of the sea

are being ascribed chiefly to changes in or beneath the hydrosphere itself without vertical movement in the land. That the latter view is more nearly right than the former can not be denied. Neither can it be denied that most of the great sea withdrawals, also many of the minor withdrawals, were immediately and chiefly occasioned by deepening of the permanent oceanic basins or by some other condition inducing negative fluctuation of the water level independent of land movement. But these changes within the hydropsphere were perhaps only seldom or never solely responsible for the migrations of the strandline. If the deepening of the oceanic basins was a broad synclinal effect of the shrinkage of the lithosphere, then we may for equally good reasons assume a contemporary anticlinal effect on the continents that must have contributed in a small or larger degree to the conditions causing general sea withdrawal. After all, then, displacements of the strandline are always connected with some body deformation of the earth.

As to the alternating withdrawals and transgressions of the sea, these seem to have occurred, at least in Paleozoic times, much more frequently than even Suess conceived. The diagrams on pages 346 and 347, illustrating invasions of seas, give a generalized idea of these migrations of the shore; but the presentation is confessedly inadequate in the matter of number and detail. To what extent land deformation contributed to the production of these broad migrations perhaps can not be definitely determined. Sea filling, continental attraction, deepening of oceanic basins, and the equatorial heaping of waters incident to accelerated rotation of the earth about its axis at times of pronounced shrinkage, the last suggested by Suess and more recently by Schuchert (Bull. Geol. Soc. America, vol. 20, p. 505) as possibly important, are all forces or processes that may have operated concomitantly or separately in producing displacements of the strandline. The forces being in part compensatory, the advance or retreat of the waters, as the case may be, is the resultant of their variant activities. While the competence of these various factors to effect general submergence or emergence is admitted, it is denied that this fact necessarily excludes the operation of deformative movements within any part of the land-masses themselves.

That the marginal areas of the continents were at times elevated and folded is, of course, accepted by all—even by Suess and his followers, who speak of the continents as having the character of "horsts" and of the ocean basins as being permanently "sunken areas." This authority, however, tends to the belief or conviction that the median areas of the continents are essentially stable, a conviction shared and recently expressed by Schuchert, who holds "that the continent (North America)

is a horst, that the great medial region remained unmoved, while the margins were often folded and elevated. The seas periodically flowed over this medial land—in fact, were elevated over it—owing to the detrital materials unloaded into the oceanic areas, thus filling them and causing them to spill over on to the lands."[36]

I cannot subscribe to this view. On the contrary, though accepting the idea of permanent oceans and continents, it seems to me that the crust of the lithosphere, not unlike the more mobile hydrosphere, was subject to periodic movement away from the poles; that the surface of the lands was exceedingly unstable and that this instability pertained, though in an inferior degree, to the median areas as well as to those along the borders of the continents. Schuchert's paleogeographic maps, indeed, offer convincing proof of such instability. The general nature and the reciprocal features of these "small movements" are excellently stated by Chamberlin and Salisbury. (Geology, vol. 1, 1906, pp. 540.)

DIFFERENTIAL VERTICAL MOVEMENTS OF THE LITHOSPHERE

Tilting of land areas.—The varying distribution of marine deposits of successive ages naturally suggests differential upward and downward movement of the lands as the immediate cause of such variation. If the submergences had been occasioned solely by rise of the waters, whatever the cause of the overflow, the successive submergences of the relatively featureless lands would have been always similar in geographic pattern and different only in lateral extent. In fact, a general similarity or repetition of old patterns is recognizable, but there is also exceeding diversity of expression, and the significant feature is that this diversity is often greatest when directly succeeding stages are compared. One stage may be very different from the next, but the third or fourth again may be very much like the first. Only oscillatory movements of the land surfaces could produce such results. The area affected by such movements may be very large, as, for instance, during the middle Ordovician and middle Silurian, when nearly half of the continent of North America was involved. During this period the Gulf waters seem at certain times to have been completely withdrawn from the southern part of the

[36] Bull. Geol. Soc. Am., vol. 20, p. 438.

It is to be remarked that this statement is inconsistent with others of this writer in the same paper. Thus, on pp. 501 and 502, he speaks of the medial areas being buckled and warped and of variable local loading and compensatory isostatic vertical movements. Suess also noted conditions that are not in harmony with his general conclusion. Thus, for instance, he says (Antlitz der Erde, English edition, pt. 3, p. 545): "A close examination of the stratified series often leads us to suspect the existence of numerous smaller oscillations which are hard to reconcile with eustatic processes."

continent, the middle and northern parts at such times being tilted so that the boreal sea extended southward beyond Chicago and occasionally as far as northern Tennessee. Possibly the invasions incident to such broad tilting were slightly accentuated, according to the theory of Schuchert (Bull. Geol. Soc. America, vol 20, page 505), by the return to the poles of waters previously piled up at the equator during periods of active earth shrinkage. However, assuming essential permanence in location of the poles, it is inconceivable that such returns could by themselves produce the condition of advance in the north and retreat in the southern States, the latter, according to theory, being in latitudes of negligible change in water level. But granting that for some unknown cause they were competent, then the exclusion of the Gulf waters would have continued to the next period of great shrinkage—a prohibition that we have no reason to believe obtained. Hence, even these extensive reversals of sea invasions are regarded as unquestionably indicative of differential vertical movements. (See figure 8, page 407.)

These north-south tiltings of the continent are relatively modest phases of diastrophic movements of a high order of magnitude that are expressed in a more striking and indubitable manner by marked orogenic phenomena along the southern borders of the northern tier of continents. The crustal folds which have resulted from this series of movements have a general east and west strike and are especially well developed in areas adjacent to the Mediterranean and Indian seas in the eastern hemisphere, and to the Gulf of Mexico in the western. The available data suggest a tendency of the outer part of the crust to move away from the poles, with sinking in the polar regions and corresponding heaping of the crust equatorially. This process long continued might be expected to result finally in great depressions of the lithosphere about the poles and in nearly compensating elevations within the median east-west zones of orogenic activity. For two reasons chiefly the present conditions fall short of the expectations. First, the elevated areas have been subject to consequent acceleration of erosion, the disparity in relief being thereby reduced; and, second, local loading of the areas in which mountain-building was in progress (the loading being occasioned by folding and consequent heaping of the superficial crust) unsettled the isostatic equilibrium, and thus aided erosion in bringing the high parts back to former levels. Sedimentary loading of adjacent submerged areas assisted by tending to drag the high lands down with them. Finally, with sinking going on, say, in lands bordering the Gulf of Mexico, deep-seated, northward flowage of rock matter doubtless took place, presumably resulting in refilling of the polar depressions from below and in gentle, upward movement of the

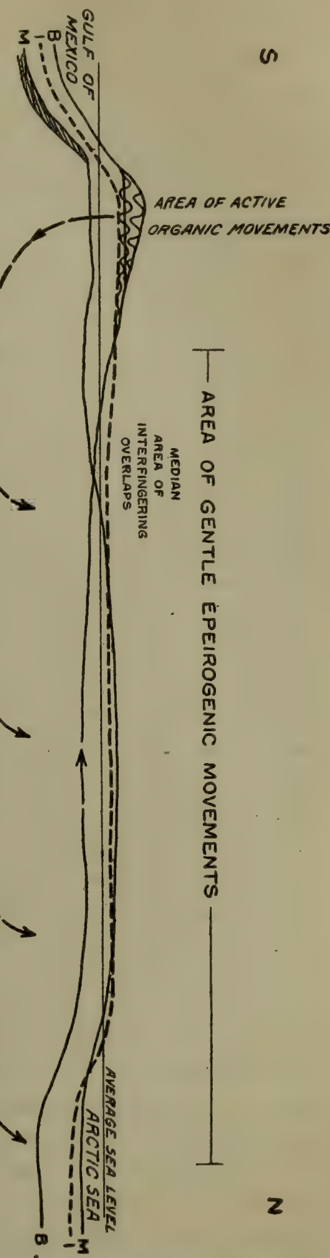


FIGURE 8.—*Schematic Sections of North America from the Arctic Sea to the Mouth of Mississippi River*

The diagram illustrates tilting of continent in Ordovician and Silurian times and isostatic adjustment following southerly thrusting of the earth's crust. M = southerly tilt when the Gulf of Mexico invaded. B = northerly tilt when the Arctic Sea transgressed. I (dashed line) = intermediate stage in which the whole continent is emerged. In the B stage the area of active orogenic movements is represented at its maximum elevation. This was followed by subsidence and erosion to the submerged plane shown beneath it in profile M. Lower dashed line and arrows represent assumed deep-seated northward flowage induced by overloading of southern areas.

central and northern parts of the continent. Something like this is thought to have occurred repeatedly, and probably many times, during past geological ages, and the theory would serve very well in explaining the alternating north and south tilting of the surface of North America that is so clearly indicated by the distribution of Ordovician and Silurian faunas and sediments described on pages 367 to 371.

Two groups of movements—The movements defined. — Diastrophic movements are divisible into two generalized and not sharply differentiated groups, (1) those that are active and relatively impulsive in operation, and (2) those that are relatively gentle in operation and much more gradual in the production of results. The former are chiefly responsible for the wrinkles of the earth's crust, and their function is primarily orogenic. On the continents these relatively active movements originated and repeatedly rebuilt the mountain chains of the present day; in the oceanic basins they occasioned the great undulations of their bottoms. Though the same

in ulterior causes and effects, there is still some difference in the progress and final results of the movements in the continental and oceanic parts of the crust. These differences are due to a secondarily contributing causal factor operating in the former but absent in the latter. On the continents, namely, the reduction of the inequalities of the surface is produced as much by erosion of the mountains as by filling of the hollows, whereas the undulations of the oceanic bottoms are lessened, if at all, chiefly and perhaps solely, by greater accumulation of deposit in the depressions. The doubt expressed by the words "if at all" is based on the suggestion that subsidence, due to depositional loading and to inherent differences in specific gravity, may have maintained topographical relations pending the periodic revivals of diastrophic activities when the inequalities must have been accentuated. Accordingly the aggregate vertical displacement is much greater on the continents than within the oceanic basins.

The movements of the second group consist chiefly of gradual displacements occasioned by temporary accommodation to slowly accumulating stresses. These stresses are produced by suboceanic spreading on the one side and continental creep on the other, by depositional loading, and by all other causes tending to disturb isostatic equilibrium. Ulteriorly, then, the causes of the movements are essentially the same in both groups. They differ in that the movements of the second group are connected with the early accumulation phases of the stresses, in that they are relatively continuous in operation and comparatively local in their contributions to orogenesis. Those of the first group, on the other hand, are associated with the saturated stages of accumulation of stresses, are likely to be relatively impulsive in operation, and their results in the way of mountain-building are geographically more extensive. Their dynamic effects differ further in that those of the first group are of a higher order, and that the structural readjustments within the lithosphere caused by them are as a rule more permanent.

Varying effects on the strandline.—From the standpoint of stratigraphy the greatest difference lies in their respective effects on the same parts of the strandline, namely, the impulsive movements of the first group tended always to land elevation and sea withdrawal from the eastern, western, and southern sides of the continents of the northern hemisphere; hence they resulted in negative displacements of these parts of the shoreline. The gentle movements of the second group, on the contrary, tended in the main to gradually lower these parts of the continents and consequently induced sea transgression and partial submergence of their flanks. Coming to the northern side of more particularly the North Amer-

ican continent, it is found that the displacement of the strandline is quite different from that noted on the other sides. Here, as explained and illustrated on page 407, the movements of the first group caused gentle though very widespread subsidence. In other words, while the results of the movements are strictly orogenic on the east, south, and west borders of the continent, on the northern side they resulted in sinking and gentle warping of wide land areas, and thus are distinctly epeirogenic in character. When the subsidence proceeded to the submergent stage, as in the late Black River, the earliest Trenton, and in one or more of the Richmondian ages,[37] the northern sea transgressed very broadly and with extraordinary rapidity over the great median flats of the continent. Proof of the relative rapidity of these transgressions is seen in the small thickness of the deposits of seas invading from the north, this being out of all proportion to the great extent of territory covered by them. The seas invading from the east, south, and west as a rule not only laid down much greater thicknesses of sediment, but the inland extent of the deposits was very much less, and the rate of sea advance, as indicated by the relative abruptness of the inland overlaps of the successive beds, was much slower.

From the foregoing it will be observed that the great north-south differential movements referred to under the term "continental tilting" are partly assignable to both groups. The northward tilt occasioned what may be called the submergent phase of the total result of a movement of the first group that manifested itself more typically in the south by crustal folding and land building. Both phases suggest impulsive and on the whole rapid development. The reversal of the tilt, occasioned by elevation of the northern and median parts of the continent and subsidence in the southern, was a much slower process and therefore belongs to the second group.

All other tilting of continental areas, especially the "minor tilting" of such prevailingly *positive* inland domes as the Cincinnati, Nashville, and Adirondack uplifts, which oscillated in east-west directions more commonly than north-southwardly, is similarly attributable to movements of both groups. However, in these cases the reversal or decided modification of the tilt of the domes is probably always more or less impulsive in origin and consummation; hence due to a movement of the first group. Apparently, then, only the gradual subsidences and consequent submergences of one or another of their sides may be attributed to movements of the second group.

[37] It should be admitted here that it is only when such northern invasions were accomplished that the differential character of these movements is demonstrable on competent stratigraphic and faunal evidence.

A reasonable deduction from these considerations is that, with the exception of the noted invasion by polar seas, all submergences are directly ascribable to movements of the second group, and that all negative displacements of the strandline, excepting again the retreat of polar waters, that are not purely local in development, are relatively impulsive and therefore due to or connected with earth movements of the first group.

Discrimination of general earth movements.—The details of the most active movements which resulted in great land growth are often very difficult to decipher. In these cases the competent sedimentary and organic criteria are, if not wholly, at least mostly, confined to parts of interior basins and to extracontinental areas now inaccessibly buried. We have, therefore, no adequate means of discriminating between the grander and the less important movements that took place during a highly emergent phase of the continents. Indeed, the land record is as a rule drawn in broad and none too definite lines. When it indicates diastrophic movements, the record shows both the major and the minor movements in a composite picture in which the individual occurrences can not be satisfactorily discriminated. Moreover, since the movements exerted themselves chiefly in areas and lands offering the least resistance, and as these non-resistant areas grew continually weaker and were thus perpetuated, it has become extremely difficult to say how much of the composite effect really belongs to the period to which it is commonly assigned and how much to preceding and succeeding periods. Appalachian folding certainly was not all accomplished at one time or during a single period. It began in a pre-Cambrian era and probably is going on in the present (see pages 436 to 439).

The grandest of the movements referred to in the preceding paragraph are thought to have occurred about the close of the eras. As they left deeply impressed records and their periods were long, the times of their occurrences are recognized the world over. Other movements of major import are indicated in the intersystemic intervals. These also are recorded in a recognizable manner—chiefly by evidence of great sea withdrawal—on all of the continents. Then there were movements, defining series, groups, and the more important formations, that resulted in similar though not always general evacuations of the marine continental basins. These, too, have left intercontinental physical records that will be correlated more or less definitely when the known facts are revised and mere matching of fossils shall have given way to comprehensive modern methods of determining stratigraphic equivalence. It will be

done by correlating negative displacements of the strandline on corresponding parts of the several continents rather than faunas and floras.

Regarding the slow movements that induced positive displacements of the strandline, except on the polar sides of the continents, their records are to a large extent clearly preserved in the accessible deposits of the continental seas. Detailed stratigraphic studies in the Appalachian region and on the flanks of the Adirondack, Ozark, Cincinnati, Nashville, and Wisconsin domes have brought out much interesting information respecting their operation.

These studies show that shifting of the strandline, which, from the viewpoint of the systematic stratigrapher, is the most important of the criteria of diastrophism, is recorded, organically, (1) by abrupt changes in the aspect of faunas, and (2) by the sudden appearance or reappearance of species and genera in deposits of continental seas (see examples noted on pages 298, 302, and 514); physically it is recorded (1) by more or less obvious breaks and hiatuses in the stratigraphic column indicating sea withdrawals, (2) by changes in the character of deposits, especially when this involves abrupt transition from biochemical and organic sedimentation to clastics, or a change from land to marine deposition, and (3) by overlaps of marine sediments. The relative elevation and subsidence of the continents, each taken as a whole or considering only parts of each, also the varying climatic and other superficial conditions, are recorded by local or more or less general changes in character and volume of marine and land deposits.

The rate of transgression of stratigraphic overlaps is dependent on the relative relief of the land in course of submergence. It is most rapid and widest in extent when baseleveling of the lands, whether due solely to subaerial erosion or assisted by general subsidence and continental tilting, has been most nearly accomplished; and it is partly for the same reasons that the introductory submergence of a period or epoch sometimes spreads farther and more uniformly than its succeeding stages (see page 338). The rate and extent of the submergence, especially of the eastern, western, and southern parts of northern continents, therefore affords a means of estimating the duration of the emergent intervals. The character and volume of clastic sediments following a stratigraphic hiatus and the rate of change from clastic to non-clastic limestone deposition may also be used to the same end.

Minor and local tilting—Examples.—There were many relatively local changes in the strandline of continental seas that seem to have been caused by correspondingly local differential vertical movements of the

lithosphere. I do not refer to movements connected with vulcanism. On the contrary, the best examples of the kind in mind are found in areas but rarely or not at all affected by vulcanism. These differential movements indicate actual elevation of one area, while another near by was sinking, and a reversal of the movement in a succeeding time. The phenomenon might be likened to a platform supported in the middle and tilted alternately to the east and west, and at other times to the north and south. The condition is recognized by the alternate absence and presence of sediments on opposite sides of the tilting platform. Excellent examples are found in comparing sections of Ordovician bands met in crossing the Appalachian valleys from east to west. It is thought advisable to cite as many instances as the space available will permit, first, so that the principle of tilting movements may be established, and, second, because it brings out the kind of evidence on which beds hitherto believed to be contemporaneous are shown to be of different ages. Additional examples are discussed in the review of the principles of correlation by diastrophic movements (see pages 535 to 569).

The varying composition of the Chambersburg limestone in southern Pennsylvania, described in an earlier part of this paper (page 321), shows this kind of oscillation in a very satisfactory manner. In the western belts of this formation, passing through the vicinity of Mercersburg, the lower 100-200 feet of the Chambersburg consists of a subcrystalline limestone (correlated with the upper Chazy) that is entirely absent in the eastern belt, which passes southward from the town of Chambersburg, Pennsylvania, through Maryland, and thence on into Virginia. The succeeding Black River zones, the first and second of which (Lowville limestone and Echinosphærites bed) are widely distributed in southeastern America, are present in both the eastern and western belts, though subject to considerable variation in thickness, character, and faunas. But the overlying last beds of the Chambersburg are developed only in the eastern belt. The next following argillaceous limestone and shale of the Martinsburg formation again overlaps from the east over the western (Mercersburg) bands.

Oscillation in the southern Appalachian Valley.—The same type of oscillation prevailed in the southern part of the Appalachian Valley. In northeast Tennessee, for instance (see map and figure 9, page 414), the Canadian deposits hitherto included in the Knox are wanting in the Eopaleozoic bands in the middle and western parts of the valley, but are very strongly developed on the east side. Before that the great Ozarkian Copper Ridge division of the Knox had been excluded from the east side

of the valley and confined to the middle and western parts. During this time, then, the valley as a whole was tilted to the west, while in the Canadian the east side was depressed and the middle and western parts relatively elevated. The Canadian is followed by the Stones River limestone. Of the three divisions of this series, the lowest is best developed on the west side and thin or locally entirely absent in the middle and eastern bands. Where present in the latter it is represented by the Mosheim limestone. The middle division of the Stones River again is thickest in the western strips, rather well developed but lithologically distinct in the eastern part of the valley, where it constitutes the Lenoir limestone, and entirely absent in the intermediate area. Except the Mosheim, which is locally present, no rocks of Stones River age are found in the valleys flanking Copper Ridge. As to the upper division of the Stones River, this is found only in the western part of the valley. Presumably it was deposited in this region only in the Clinton trough, the Pearisburg, Knoxville, and Athens troughs having been in a state of emergence at this time.

In the next or late Chazyan stage, represented in Tennessee by the Blount group, the southern Appalachian sea was confined in northeastern Tennessee at times to the eastern, at other times to the middle parts of the valley. As a rule, sections in the Athens trough (on the east side) and the Clinton and Newman troughs (on the west) contain no beds of the early part of this stage, but occasionally in the latter, as at Clinton, and in Mulberry Valley, northwest of Powell Mountain, Tennessee, a subcrystalline limestone is found whose fauna, lithologic character, and stratigraphic position all clearly suggest the Holston. Following the Holston, we find the Tellico and Ottosee formations in the medial area, the Tellico and Athens in the east, and the deposits of the Black River group, beginning with a strongly developed Lowville, mostly on the west side of the valley. As elsewhere, considerable minor oscillations occurred also in this region during the Black River, but the movements were too complicated to be satisfactorily described in brief.

During the remaining ages of the Ordovician the oscillations in the Appalachian valley generally seem to have been relatively wider in scope than before. In east Tennessee the submergences and emergences appear to have affected the whole valley and at times extended westward to or beyond the Cincinnati axis. Deposition of red, Moccasin-like sediments began in the west middle bands of the valley in early Black River time, but the typical Moccasin, which is late Black River or early Trenton in age, extended and possibly overlapped eastward and, according to present evidence, passes into the calcareous Bays sandstone in the eastern

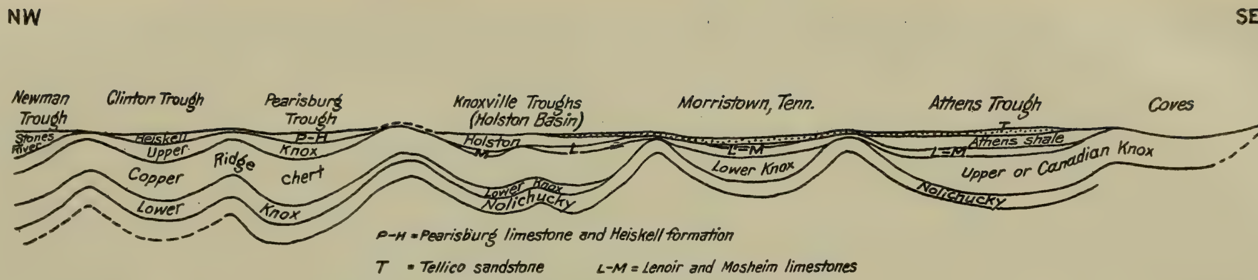
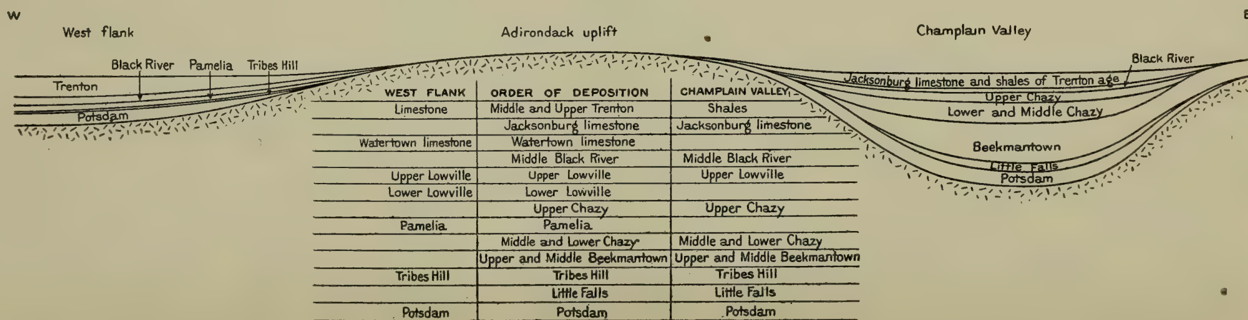


FIGURE 9.—*Sketch giving an approximate Idea of the southern Appalachian Troughs at close of Tellico Sandstone Sedimentation*

It is intended to show the distinct distribution of the three divisions of the Ozarkian Knox dolomite, of the eastern or Canadian "Knox," and of the Mosheim, Lenoir, Athens, Holston, and Tellico formations of the Ordovician.



WEST FLANK	ORDER OF DEPOSITION	CHAMPLAIN VALLEY
Limestone	Middle and Upper Trenton	Shales
	Jacksonburg limestone	Jacksonburg limestone
Watertown limestone	Watertown limestone	
	Middle Black River	Middle Black River
Upper Lowville	Upper Lowville	Upper Lowville
Lower Lowville	Lower Lowville	
	Upper Chazy	Upper Chazy
Pamelia	Pamelia	
	Middle and Lower Chazy	Middle and Lower Chazy
	Upper and Middle Beekmantown	Upper and Middle Beekmantown
Tribes Hill	Tribes Hill	Tribes Hill
	Little Falls	Little Falls
Potsdam	Potsdam	Potsdam

FIGURE 10.—*Section showing East-west Oscillation of the Adirondack Uplift and consequent Differences in the sedimentary Sequence on these two Sides*

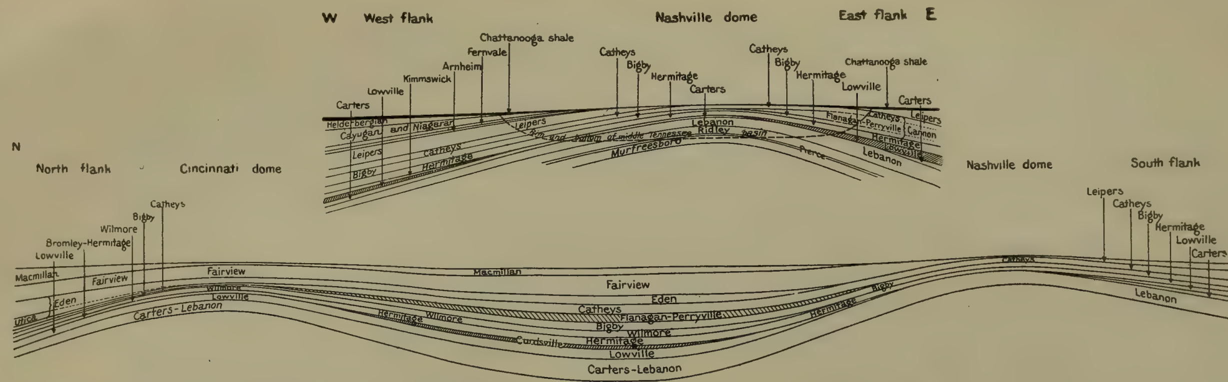
part. The typical Bays is succeeded by shales and sandstones evidently of Cincinnatian age. If correctly determined the succession in Bays Mountain suggests an hiatus between the Bays sandstone and the succeeding formation corresponding to at least the middle and upper Trenton. West of Bays Mountain, as in Clinch Mountain, the Moccasin is succeeded by a great series of shaly limestone and calcareous shale, mapped as "Sevier shale," the lower part of which, according to its fossils, is of Trenton age. Farther west, in the Clinton trough, the equivalent Trenton deposits are limestone, and hence were referred by the geologists who mapped this area to the Chickamauga limestone. During the greater part of the Trenton, therefore, the Athens trough seems to have been emerged and the sea confined to the west of Bays Mountain. The Eden sea, however, spread farther eastward, as did also the red calcareous sandstone which succeeds it. The latter follows the great valley from northern Alabama to southern Pennsylvania. It is of late middle (Fairview) Cincinnatian (excluding the Richmond) age. In Pennsylvania it has been incorrectly referred to the Juniata sandstone, which is a more westerly and younger formation. In northern Virginia it constitutes the lower part of the Massanutten sandstone. On maps of southwestern Virginia and eastern Tennessee, published by the U. S. Geological Survey, it is referred to, apparently erroneously, as Bays sandstone.

According to the foregoing brief account, the Ordovician part of which is graphically illustrated on page 544, it appears that, beginning with the Copper Ridge chert and ending with the last of the Ordovician stages, the attitude of the Appalachian Valley troughs in east Tennessee was modified many times by differential vertical movements and the distribution of the successive formations correspondingly changed. Similar and perhaps even more striking oscillations occurred in central Alabama.

Oscillations of the Adirondack uplift.—Equally convincing evidence of local differential movement of the lithosphere is brought out by comparing the sections of Ordovician and earlier rocks on the east and west sides of the Adirondack uplift. Thus, while the lower beds of the Beekmantown occur on both sides, the later deposits of this series are found only on the eastern side in the Champlain Valley. Non-deposition continued on the western side, while the lower and middle divisions of the Chazy were being laid down on the east side. Then the area of deposition was shifted to the west side, where the upper Stones River, or Pamelia, limestone is found resting on beds of early Beekmantown age. No deposits corresponding to the Pamelia are found in the Champlain Valley, where the upper Chazy, which, on the other hand, is wanting on the west side, rests on the slightly eroded middle Chazy. The succeed-

ing Black River group is represented on both sides, following the upper Chazy on the east and the Pamelia on the west. Minor oscillations with local warping occurred here at various times during the Mohawkian, the formations of the Black River and Trenton groups varying greatly in distribution and character, so as to clearly indicate frequent interruption of sedimentation. The details of the movements are too complex to admit of satisfactory treatment in brief, generalized statements. The sections and tables in figure 10 will help the reader to grasp the situation.

Differential movements of the Cincinnati geanticline.—Similar oscillations of the flanks of the Cincinnati and Nashville domes occurred. In the former the principal movements consisted of alternate tilting to the north and south. Thus, while the Stones River limestones apparently were spread evenly over the whole Cincinnati dome, we know from outcrops along Kentucky River and deep wells to the north of Ohio River that the Lowville limestone is developed chiefly on the south flank. A greater relative depression of this side obtained during the deposition of the Curdsville limestone, which is entirely unknown on the north flank. Complete and seemingly nearly equal submergence of at least the flanks of the dome prevailed during the Hermitage, which is the first of the Trenton formations. Some variation of attitude is indicated during the Wilmore. The apex of the dome was located much nearer Cincinnati than usual, and the Wilmore sea, which laid down nearly 100 feet of limestone in central Kentucky, seems to have failed not only to cover the whole dome, but even to encircle it on the north. Detailed comparisons of sections prove the absence of Wilmore deposits in the vicinity of Cincinnati and suggest a small peninsular projection from unsubmerged areas to the north. The succeeding Bigby limestone once more completely encircled the dome; but the next following Flanagan and Perryville limestones are confined to the south flanks, the former covering them rather generally, while the latter was laid down only in narrow embayments. The Perryville was succeeded by the Catheys formation, which again encircled and possibly completely covered the dome. In this and the preceding stages the northern flanks were more commonly emerged and at no time so deeply submerged as the southern side. In the following stages, however, the reverse condition predominated. The first of the succeeding deposits is the Gratz shale, which is best developed on the northwest margin of the dome along Kentucky River, but is recognized in a thinner bed at the mouth of Licking River opposite Cincinnati and somewhat doubtfully at several localities in Ohio and Kentucky from 20 to 30 miles up the Ohio. It seems to be absent entirely on



CINCINNATI DOME NORTH FLANK	NASHVILLE DOME SOUTH FLANK	ORDER OF DEPOSITION		NASHVILLE DOME WEST FLANK	NASHVILLE DOME EAST FLANK	
			Chattanooga shale	Chattanooga shale	Chattanooga shale	
			Helderbergian	Helderbergian		
			Cayugan and Niagaran	Cayugan and Niagaran		
			Fernvale	Fernvale		
			Arnheim	Arnheim		
Macmillan			Macmillan *			
Fairview	Leipers		Fairview–Leipers *	Leipers	Leipers	
Eden: McMicken		* Eden	McMicken			
Eden: Southgate		* Eden	Southgate			
Eden: Economy		* Eden	Economy			
Eden: Utica		* Eden	"Utica"			
Catheys	Catheys	* Cannon	Catheys	Catheys	Catheys	Cannon
		* Cannon	Perryville		Perryville	Cannon
		* Cannon	Flanagan		* Flanagan	Cannon
Bigby	Bigby	* Cannon	Bigby	Bigby		Cannon
Wilmore			Wilmore *			
Bromley–Hermitage	Hermitage		Hermitage *	Hermitage	Hermitage	
			Curdsville *			
			Kimmswick	Kimmswick		
Lowville	Lowville		Lowville *	Lowville	Lowville	
Carters	Carters		Carters *	Carters	Carters	
Lebanon	Lebanon		Lebanon *	Lebanon	Lebanon	
			Ridley			
			Pierce			
			Murfreesboro			

* Ordovician formations in depression between Cincinnati and Nashville domes

FIGURE 11.—*Diagrams showing Variations in Distribution of Sediments between and on the Flanks of the Domes of the Cincinnati Geanticline*

the southern margin. The fauna of the Gratz is much like that of the Hermitage. Both probably entered the continental basins through the Mississippi embayment, though the Gratz phase is wholly unknown (probably concealed by overlapping later deposits) south of northern Kentucky.

Except that it was followed by more general emergence, the attitude of the Cincinnati dome remained nearly the same as in the Gratz stage to the latter part of the Eden. The last of the Utica (Fulton shale), overlapping from the north, extends a short distance over the northern flank of the dome and rests with slight local unconformity on the Gratz. Submergence continuing, the overlying shales lap farther and farther southward, the last of the Eden having possibly covered the whole of the present dome. During most of the succeeding Maysville stages the whole of the Cincinnati uplift seems to have been almost evenly submerged. At any rate, no decided tilting of its surface is suggested by the known distribution of the formations of this group.

Very similar north and south tilting of the Nashville dome is clearly indicated by evidence already in hand, but details remain to be worked out. Considerable progress, however, has been made in determining the east and west oscillations, which seem to have been of greater consequence in the stratigraphic history of this dome. In comparing the sections on the east and west flanks it is found that the Lebanon limestone of the Stones River group is about equally well developed on both sides, though probably absent locally on the northwest side. At any rate, the Lebanon has not been recognized in the Wells Creek uplift, in which older deposits come to the surface. The succeeding Carter limestone, however, is found only on the west side, while the Lowville is seen only on the east, north, and south sides. The Kimmswick again is absent on the east flank, but is locally present on the west margin. Next comes the Hermitage, which is found on both sides and probably encircles the dome. The Wilmore formation of the Kentucky section is unknown in Tennessee, but the Bigby, which follows it in time, occurs, like the Hermitage, on both sides. Nearly 200 feet of limestone, forming the middle two-thirds of the Cannon limestone, follows the Bigby on the east side, but is entirely unknown on the west margin. The succeeding Catheys formation again has a more general distribution, being found wherever the Bigby and Hermitage occurred before it. The shales of the Eden group are unknown in middle Tennessee, but the Leipers formation, which is essentially the same as the lower two-thirds of the Maysville in the Cincinnati region, is well developed on the north and west sides, though absent along the greater part of the eastern border.

Judging from the distribution of succeeding deposits, this westerly tilt of the Nashville dome seems to have been maintained to the close of the Devonian, when the widely transgressing Chattanooga shale encircled and possible spread over the whole dome.

That the vertical movements of the two domes of the Cincinnati geanticline were not uniform or alike—in other words, that the movements which affected the two domes often differed in direction and volume—will be apparent on comparing the above brief accounts. Thus, while alternate east and west tilting of the Nashville dome is clearly indicated in the closing stage of the Stones River and during the Lowville by the absence of the latter on the west side and the absence of the Carter limestone on the east, no corresponding differential movements of the Cincinnati dome are suggested by the areal distribution of the equivalent deposits in Kentucky. Again, whole formations present in Kentucky, as, for instance, the Wilmore and the Eden, are absent in middle Tennessee, such facts being interpreted as indicating relative elevation of the Nashville dome, while subsidence of the Cincinnati dome was in progress. Finally, though the submergences which encircled either of the two domes are usually common to and alike in both, as the Hermitage, Bigby, Catheys, and less clearly the Maysville or Leipers, the submergences which affected only a part of the circumference of either are usually different in the direction of the tilt. Thus, while the Cincinnati dome was tilted to the south or southwest during deposition of the Flanagan and Perryville limestones, the Nashville dome was tilted to the northeast.

Oscillations in the Mississippi Valley.—Essentially the same kind of differential movements affected the Ozark, Arbuckle, and Wisconsin uplifts during the Canadian and Ordovician. In these instances, however, it is much more difficult to establish the stratigraphic relations of the beds on opposite sides of the uplifts. In the case of the domes of the Cincinnati geanticline the same formations are found on both uplifts, and the varying movements of the domes have so arranged the deposits that the sedimentary record in the one supplements that in the other and establishes a succession that could not be fully worked out from either. If we did not know that the Lowville (Tyrone) limestone rests on the Carter limestone at Highbridge, Kentucky, it would have been difficult to prove to the satisfaction of stratigraphers that the beds resting on the Lebanon limestone on the east side of the Nashville dome are younger than the Carter limestone, which follows the Lebanon on the west side. The faunal evidence, it is true, suggested the absence of

the Carter on the east side of the dome, but until it was proved by unquestionable stratigraphic evidence that the observed differences in the faunas found in the beds next overlying the Lebanon on opposite sides of the dome are truly indicative of successive ages and not merely local variations of a contemporaneous fauna, the final determination of the ages of the respective beds must necessarily have awaited further evidence.

Having established differential tilting on the Adirondack, Cincinnati, and Nashville uplifts and proved the consequent absence of deposits on one side that are present on the other by actual superposition elsewhere of formations that seem to occupy corresponding positions on opposite sides of the alternately tilted domes, it is thought reasonable to infer similar tilting of the Wisconsin, Ozark, and Arbuckle uplifts. With respect to the Wisconsin dome, much evidence tending to prove such differential movements has accumulated, but, as intimated, the actual order of events is so difficult to prove and the evidence so intricate that it is impossible to do it justice in the limited space here available. On some future occasion it is hoped to publish a full discussion of the perplexing structural and stratigraphic problems encountered in the Eopaleozoic rocks of the upper Mississippi Valley.

The movements and consequent unequal distribution of the deposits within and adjacent to the area of the Ozark uplift are likewise being described in full for a special work on that geologically important area. Here it will suffice to say that tilting of this uplift is clearly indicated by a number of formations covering its flanks. Particularly notable among these are the Yellville, Kimmswick, and certain Silurian and Devonian formations which occur on the south and southeast and are absent on the north and northwest flanks and the extensions southward from Iowa of the Decorah formation, the Prosser limestone, and a Niagaran dolomite, which formations occur on the northeast margin and are absent on the south and west sides.

Yellville oscillations.—Of these formations the Yellville is of special interest because it is not only confined to embayments of the old shore of Ozarkia in northern Arkansas and southern Missouri, but also because the formation varies greatly in the distribution of its members. In thickness it ranges from 0 to about 200 feet, but the maximum development in most of the embayments is less than 150 feet. Neither of these figures, however, does justice to the aggregate maximum development of all the members that are distinguished in Arkansas. This may reach 300 feet or more, but satisfactory measurements are difficult to make because vertical exposures are few, and most of the outcrops occur on weathered dip slopes.

So far as determined, the oldest member is a light, bluish gray dolomite, about 40 feet thick, and seen only in Lawrence County, Arkansas. This member is of unusual interest because it contains the only known occurrence of the Phyllograptus fauna in unfolded interior rocks.

The second bed is thin, but contains a well-marked fauna and is widely though locally distributed. It is absent in the vicinity of Yellville, but is found here and there to the east in Lawrence County and to the west in Christian County, Missouri. The fauna, though probably somewhat older, reminds greatly of the Fort Cassin facies in the Champlain basin.

The third bed, also, is thin (0-20 feet) and has been observed only in the Yellville embayment. It is a conglomeratic porous chert, usually very fossiliferous. The fauna consists chiefly of small, slender gastropods, *Leperditia*, and a brachiopod like *Dalmanella electra*, and most of the species are confined to this zone.

Not to enter too much into detail, the fourth zone seems like the first and a following sixth, to be confined in Arkansas to the Lawrence County embayment, while the fifth, which makes the bulk or whole of the formation in the Yellville and more western embayments, is absent there.

Post-Ordovician oscillations in North America—General character.—That the foregoing examples of oscillation of seas, due to differential vertical movements of comparatively limited but

FIGURE 12.—*Diagram showing Sections of Embayments in southern Flank of Ozarkia, containing Canadian, Ordovician, and Silurian Deposits*

The section extends across northern Arkansas from the border of the Tertiary at Black Rock to Sulphur Springs, near the northwestern corner of the State. Locations and thickness of beds approximate

long enduring and definitely established areas of uplift, are mostly of Ordovician age, will probably be ascribed to the fact that the rocks of this period have received a larger share of my stratigraphic and paleontologic studies than others. But this is not the true reason, for much evidence has been gathered to prove that essentially similar oscillatory movements occurred in preceding and succeeding Paleozoic periods. The true reason is that minor local tilting of the kind described is more readily determined and seems, indeed, to have been more prevalent during the Ordovician than in other periods. The evidence in hand leads to the inference that in the other periods the movements were broader in scope. Largely on this account their effects on the distribution of deposits and faunas is less easily ascertained. However, the lack of clearly defined and abundant faunal associations in the rocks of certain ages doubtless contributes not a little to the difficulty of acquiring detailed knowledge concerning local migrations of the strandline.

Early Silurian oscillations in North America.—Movements of a differential vertical character, simulating those of the Ordovician, except that as a rule they affected relatively wider areas, are clearly indicated in the early and middle Silurian. Post-Ordovician sedimentation in America is believed to have begun with the Dubuque limestone, an irregularly distributed and sparingly fossiliferous thin formation in the upper Mississippi Valley. The age of this bed has not been positively determined, but for the present it seems preferable to class it with the Maquoketa in the Richmond than with the underlying Ordovician deposits. It is limited both above and beneath by unconformities and, so far as known, confined to the north. The Arnheim shale, which is provisionally assumed to succeed the Dubuque, is known only on the flanks of the Cincinnati dome and locally in west central Tennessee. This distribution, together with the fact that its fauna consists chiefly of unquestionable though strongly modified derivatives of the Maysville fauna of the same areas, indicates its southern origin. In Tennessee it is succeeded and overlapped by the Fernvale, a well marked and widely recognizable zone. That differential movements intervened is proved by the fact that whereas the Arnheim is well developed in the Cincinnati region and wholly unknown in Arkansas, Missouri, and Illinois, the reverse is true of the Fernvale. Both formations contain large faunas, but very few of the species are common to the two. In view of this faunal difference, it seems improbable that both invaded from the Gulf of Mexico. On the other hand it seems unlikely that the characteristic and abundant Fern-

vale fauna could have been overlooked in Canada if it invaded from the north.

In Ohio and Kentucky the Arnheim is followed by the Waynesville and Liberty formations, but north of Gallatin, Tennessee, the Fernvale wedges in between the Arnheim and the Waynesville. Evidently differential movements had again occurred, bringing about conditions in the Waynesville-Liberty stage simulating those prevailing during the Arnheim.

In eastern Missouri and southern Illinois the Fernvale is succeeded unconformably by a southward extension of the Maquoketa shale of Iowa. North of Sainte Genevieve, Missouri, this extension, save that it is thinner, is in every respect typical of the Iowa formation. Further south, however, at Cape Girardeau, Missouri, and Thebes, Illinois, the basal part only consists of dark shale, the middle and upper parts of the zone being of arenaceous shale and sandstone—a lithological difference justifying the local designation "Thebes formation." No Richmond, nor indeed Silurian deposits of any age, are found on the north, south, and west sides of Ozarkia.[38]

The geographic derivation of the fauna of the typical dark Maquoketa shale is not positively determined. Though both the formation and its fauna are best developed in eastern Iowa, neither has been identified north of the United States, east of Wisconsin and Illinois, nor to the west of the 100th meridian. But as the fauna has its nearest relatives in the Utica, an unquestionable north Atlantic fauna, it is quite possible that the Maquoketa is represented in the supposed Utica on Georgian Bay and Hudson Strait, and that it invaded the Mississippi Valley from that direction.

The Whitewater and Saluda divisions of the Richmondian in Indiana, Kentucky, and Ohio, succeed the Liberty, but their relations to the

[38] Possibly such rocks occur farther west beneath the cover of overlapping late Paleozoics, the eastern edge of which as a rule rests on Ozarkian dolomites; but they must be very far away, since no evidence of such a condition is even suggested by the records of deep wells in southwestern Missouri. In northwestern Missouri, however, as shown by a deep well at Forest City, the strata dip into a Paleozoic basin containing Mississippian and Devonian deposits that are wholly absent where they should outcrop on the margin of the area of Ozarkian rocks. Though the well at Forest City does not reach the horizon, the probable existence of the Maquoketa shale in this basin and of an arm of this Richmond sea extending far southward from Iowa, is strongly indicated by the lithologic character and the fauna of the Sylvan shale in the Arbuckle uplift of Oklahoma. A similar connection between Oklahoma and the Iowa-Minnesota region is no less clearly suggested during the deposition of the Decorah shale and the Prosser limestone in the northern States by fossils found in the upper part of the Bromide formation and in the lower part of the Viola limestone in the southern area.

Maquoketa are not easily determined. I can not take the space to argue the question here but must content myself with the statement that after careful study it has been decided to place them above the Maquoketa. If this assignment is correct, then continental tilting had again intervened and reversed the direction of marine invasion, for the greater part of the Whitewater and Saluda faunas are undoubtedly southern in origin. It is these faunas, too, that I correlate with the typical Medina fauna of New York, the latter comprising such of the elements of the former as were suited to existence on a sandy beach. The geographic arrangement of this time then would be to the east of the Mississippi much like that marking the succeeding early Clinton or Brassfield stage.

At Cape Girardeau, Missouri, the Thebes facies of the Maquoketa shale is followed first by the Girardeau limestone, next by a limestone correlated with the Noix oolite of Lincoln County, Missouri. This is succeeded by another thin limestone representing the earliest Clinton or Brassfield of Kentucky. Of these three zones, each of which is unconformable to the next, the first or Girardeau is a southern invasion that did not extend far north in the valley, but the second evidently came in from the north, being entirely unknown in any more southern locality, while its distinctive coral fauna is very widely recognized in northern areas. The third, with its distinctive early Clinton fauna, is known from Oklahoma on the southwest to Hamilton, Ontario, on the northeast. It undoubtedly invaded the continent from the south. Considering the wide differences in distribution of the faunas and deposits of these three zones it is evident that each was introduced and terminated by a diastrophic movement.

Niagaran oscillations.—Concerning the succeeding Silurian ages, the evidence afforded by the fossils establishes beyond reasonable doubt that the dolomitic rocks of these ages in the north were deposited in waters connecting with the Arctic sea, by way of Hudson Bay, while the purer Silurian limestones of the south were in direct communication with the Gulf and middle Atlantic. To what extent the respective parts of these two series of deposits are contemporaneous has not been finally determined. The problem is exceedingly difficult, but far from hopeless. In this connection, the point of interest is to determine whether the lithologically and faunally distinct deposits were laid down contemporaneously in somewhat precariously separated seas or whether alternate tilting of the continent to the south and north, as in middle Ordovician ages (see pages 367 to 371), is a more important cause of the observed differences. That the latter condition did occur at times in the Silurian

as well as in the Ordovician period seems demonstrable, but the discussion of the evidence would require more space than is now available. Some of the faunal data bearing on this problem are discussed in the chapter on Paleontological criteria (page 485). The sequence and distribution of the Niagaran formations also are briefly commented on in a later chapter of this part (pages 558 to 561).

Devonian, Waverlyan and Tennesean tilting—General discussion.—Instances of local tilting in Devonian and Mississippian ages have not been so fully worked out as in the Silurian and Ordovician rocks. A glance at the correlation tables in Part III, however, will show that southeastern North America was subjected to very considerable oscillation during at least the Devonian and Waverlyan. Comparison of Helderbergian sections, in the Allegheny Front and Appalachian Valley, from Virginia to New York, indicates north-south and east-west tilting, much the same in character as occurred during the Blount stage of the Ordovician in Tennessee (see page 545). Something of the kind is also suggested during the Oriskany, and more certainly in the Mississippi Valley, during the Kinderhookian and Osagian. During the middle and late Devonian and most of the Tennessean the movements seem to have been broader in scope. Possibly the mass of the continent had become more rigid, the vertical movements more distributed, and the local elevations or islands in the regions of frequent submergence less subject to warping. Still, in view of the fact that the average inland extent of Neopaleozoic seas was less than that of the Ordovician, indicating a greater average elevation of the interior areas of the continent and consequently less complete submergence of the islands and of the peninsular projections from the larger land areas, it appears likely that the failure to note the differential features of the vertical movements is occasioned by lack of sufficient subsidence to effect submergence and deposition. Applying the idea to the Nashville dome it is at least possible that the east side, on which neither Silurian or Devonian sediments are found, was relatively depressed at times when the western flank was distinctly emerged. In other words, that the movement of the east side was relatively less effective, with respect to submergence, than of the west, and that the stages of subsidence on the former were never sufficient during these periods to permit submergence of parts now accessible.

Devonian and Waverlyan tilting of the Ozark uplift.—Differential vertical movements seem to have affected the area of the Mississippi Valley in a north and south direction during the middle and later stages of the Devonian and in the early Mississippian or Waverlyan.

They are suggested by the restriction of the middle Devonian Grand Tower limestone to the southeastern and southern sides of Ozarkia. No deposits corresponding in age to the greater, lower part of this limestone are known to the north of St. Louis where, on the contrary, we find formations of late Devonian ages that are not represented by sediments on the southern flanks of Ozarkia. Indeed, excepting the lower part of the "New Albany shale," which is probably of Devonian age, no unquestionable late Devonian deposits are known in Kentucky, Tennessee, Arkansas, and Oklahoma. In the next succeeding earliest Mississippian stage Ozarkia was tilted to the southeast on which side we find black shale, and often the basal sandstone, of the Chattanooga formation. The deposits of this age are not evenly distributed on the flanks of this uplift, but are found locally on the south and east sides in what I believe to have been larger or smaller embayments of the old shoreline. Before the close of the stage a considerable arm of the sea extended up the Mississippi Valley beyond the northern extremity of the Ozarkian uplift into southern Iowa, where the Sweetland shale is thought to represent this age, and to Chicago, where remains of fishes suggesting the same age are found in subterranean solution channels in Silurian dolomite.

Succeeding the Chattanooga the attitude of the area was reversed, the Louisiana limestone and equivalent deposits being found only on the northern and western flanks. That it was soon again tipped to the southeast is shown by the Glen Park limestone, which contains an interesting derivative of the southern Atlantic Hamilton fauna and has been found only on the east side of the uplift. Next comes the more or less arenaceous or calcareous Hannibal shale which is rather generally found on the north and west flanks but has not been recognized on the east side south of St. Louis nor on the south border in northern Arkansas. The upper limestone of the Chouteau has much the same distribution about Ozarkia as the Hannibal, but the following Fern Glen zone, though far from occurring in a continuous outcrop, probably encircled the island. The distribution of the Fern Glen fauna suggests general subsidence, but as the formation does not outcrop on the northwest side there must have been some tilting toward the southeast. The Burlington overlaps the Fern Glen to the north in Iowa as well as all around the Ozark island except on the east side. In fact, as is shown by remnants preserved in sink holes scattered over a large part of the dome, the Burlington probably transgressed from the west, north and south to the crystalline nucleus of Ozarkia.

While Kinderhookian deposits are always thin and but locally developed on the west limb of the Cincinnati axis, the equivalent of the Fern Glen—that is, the New Providence shale—is of fair thickness and persistently developed in Indiana and west central Kentucky. On the west side of the Nashville dome, however, it is still found only in certain small, synclinal embayments of the old shore which had previously lodged similar narrow arms of Richmondian and Niagaran seas. The Burlington proper seems entirely unrepresented by deposits in the area between the Mississippi south of St. Louis and the western side of the Appalachian Valley south of Kentucky. In this area the Osagian is represented only by the New Providence shale already mentioned and by the Fort Payne chert which is correlated with the Keokuk only. The Fort Payne facies occurs generally and with very little variation in Alabama, Tennessee, western Kentucky and southern Illinois. It is well developed also in eastern Missouri south of St. Louis, resting here, as a rule, on the Fern Glen. Finally, it is present also rather commonly on the southern side of Ozarkia, being represented in whole or part by the Grand Falls chert member of the Boone in the Joplin district of southwestern Missouri. Apparently, the Keokuk is absent entirely on the northwest and north sides of the uplift.

Tennessean differential movements.—The Keokuk was succeeded by a long period of emergence. The Warsaw represents the first deposits of the next invasion of the continent in southeastern North America. In the Mississippi Valley proper the Warsaw seems to have had an essentially similar, though more restricted distribution than the preceding Keokuk, failing to extend so far north in Iowa and not so far west on the east flank of Ozarkia. In southeast Missouri the Warsaw was positively recognized only in St. Louis, Jefferson, and Ste. Genevieve counties, where it rests on beds correlated with the Keokuk. On the north and west sides of the Ozark uplift neither of these two formations is present, but near the southwest angle, in an embayment extending northward through Washington and Benton counties in Arkansas, beyond Carthage, Missouri, more or less cherty beds, beginning with the Short Creek oolite, are found filled with fossils proving their early Tennessean age. They rest on or form an upper member of the Boone chert, a formation usually regarded as comprising deposits representing both the Burlington and the Keokuk. After a close study of the character and distribution of the rocks and faunas of the Osage group, I have been forced to the conviction that the Keokuk is sometimes but poorly or not at all represented by deposits in the Boone. In other words, the Keokuk

member of the Boone seems to be absent locally through non-deposition or possibly because of erosion prior to the Warsaw. (Further discussion of the relations of the Keokuk and Warsaw will be found in Part III.)

Considerable movement, permitting greater expanse of waters in areas east of the Mississippi River and prohibiting submergence of the flanks of Ozarkia, except on the east side, introduced the Spergen. The pattern of continental seas was again different, and not merely smaller, when the St. Louis limestone was being laid down. The Moorefield shale, which contains a very different fauna and is thought to succeed the St. Louis in time, is found only in north Arkansas and eastern Oklahoma, on the south side of Ozarkia. The formations of the Chester group or series, as developed on the east and southwest sides of this uplift, also suggest differential vertical movements within this and adjacent areas. If correctly interpreted, the east-west oscillations between northwestern Arkansas and the Indiana basin, beginning with the St. Louis and ending with the Pitkin, are essentially similar to the north-south oscillations described as affecting the Mississippi Valley proper in Ordovician and early Silurian times. (See pages 367 and 422.)

Tilting accomplished during interformational intervals.—The fact that close study of the sediments laid down on the opposite sides of these alternately tilted platforms has failed to bring out any evidence of gradual emergence—such as "regressive overlap"[39]—is of high significance in estimating the age relations of the opposed deposits. If the reversal of, say an eastward, tilt, had begun before the depositional result of this attitude of the uplift had been terminated, we should find that the geographic extent of the later deposits of the stage is successively less and less. The positive determination of detailed regressive overlap phenomena, and especially their discrimination from effects produced by erosion, is, for one reason or another, always difficult. The opposite condition of progressive overlap, however, is not only more readily established, but when it has been shown by fossils and continuity of outcrop that the last bed extends farther inland than those preceding it, we know that erosion has not complicated the problem, and that reverse tilting and sea withdrawal did not occur before the close of the stage under consideration. In Kentucky a northward overlap of the profusely fossiliferous zones of the Flanagan limestone is satisfactorily indicated by the evidence in hand. In Tennessee similarly satisfactory evidence has been found showing westward overlap across the north

[39] Amadeus W. Grabau: Types of sedimentary overlap. Bull. Geol. Soc. America, vol. 17, 1906, pp. 567-636.

flank of the Nashville dome of at least two formations, one being the Lowville, the other comprising the pre-Catheys part of the Cannon limestone.

Having proved progressive overlap for three of the Ordovician formations concerned in the process of alternate tilting of the domes of the Cincinnati geanticline, and as the present knowledge of the associated formations is merely inadequate on this point, I regard myself as justified in assuming that, at least as a rule, reverse tilting was deferred till after the close of each stage. The sharp break between the overlapping formations justifies the inference that sea withdrawal then occurred rather generally about these uplifts. Finally, the trend of the evidence strongly suggests that the reversal of the preceding attitude took place during these increased emergence intervals, so that when the waters again advanced they submerged areas on the opposite flanks of the uplifts that had not been covered in the depositional stage immediately preceding.

Except in the cases of the great north-south tilts, which involved the whole length of the continent, it is not contended that in these interformational emergences the waters were always completely withdrawn from the regions surrounding the domed areas of frequent emergence. In fact, complete withdrawal probably occurred only at times, marking the close of periods, epochs, and stages, while in the intervals separating the smaller formations the waters are thought to have retreated only as far as the deeper parts of the adjacent major downwarps. That the latter contain a more complete sedimentary record than is found in the exposed sections on the flanks of the uplifts seems scarcely open to serious contradiction—certainly not in the case of overlapping formations that may be traced by long outcrops or through records of deep wells, away from the summit of a structural dome and that may thus be shown to add more and more beds to their bases. Often the increase in thickness is rapid, as in the case of the Kimmswick limestone, which thickens from 40 feet at its outcrop, 20 miles west of St. Louis, to about 100 feet in the Belcher well within the city, and to nearly 200 feet in the Monks Mound well, 5 miles east of Mississippi River. That this buried record may often be of very considerable importance is indicated by such thin formations as the cherty Flanagan limestone, which does not exceed 40 feet, and is usually much less, in central Kentucky, while the corresponding part of the stratigraphic record in the northeastern quarter of the rim of middle Tennessee comprises a maximum thickness of something like 175 feet of solid limestone. In Tennessee it forms the greater, middle, part of the Cannon limestone, a formation that thins rapidly to the west and finally wedges

out completely in the vicinity of Nashville. In the opposite direction, in the depression between the Nashville and Cincinnati domes, doubtless an even greater development of limestone of this age is concealed by later deposits; and by "greater development" I mean not only greater thickness, but also more continuous deposition of Cannon limestone and an earlier beginning of its post-Bigby part. (See figure 11, page 417.)

Dome tilting illustrated in the peninsula of Florida.—In a search of geological maps for recent instances of dome structure suggesting differential oscillation like that of the interior uplifts described on preceding pages, at least one reasonably satisfactory case was found in the peninsula of Florida. As will be seen from the accompanying map, a semi-dome of outcropping Oligocene formations, the lower of which (Vicksburg) has a diameter exceeding 100 miles, occurs in the northwestern quarter of this peninsula. It will be observed further that, while the semicircular outline of the eastern half of the dome shows on the land, the whole of the western half is submerged beneath the waters of the Gulf. In other words, the western half of the dome has been tilted downward beneath sealevel and is now receiving a load of sediment, while the eastern half has been elevated above sealevel and is being eroded by subaerial agencies.

Should this dome be completely emerged, the deposits now being laid down would be found to overlap from the west and cover only its western side. Further, as these recent deposits rest on the Vicksburg, the contact would be unconformable and contain a stratigraphic hiatus occupied in part by the Appalachicola, Choctawhatchee, and Jacksonville formations on the east side. In short, the distribution of the successive stratigraphic units would be found to alternate in directions of overlap essentially as has been shown of the Paleozoic formations on the flanks of the Cincinnati and Nashville domes.

Possibly the whole of the peninsula is comparable to the Cincinnati geanticline, namely, the formations as mapped on the southern extremity of Florida suggest another low periodically tilted dome that might be likened to the Nashville dome. If so, the northern or Ocala dome, as it might be called, would be comparable with the Cincinnati dome.

Causes of differential oscillations of continental seas and interior land areas.—Two distinguishable though closely allied causes seem chiefly concerned in bringing about the local oscillations briefly described in the foregoing sections. The first and, more particularly in the Appalachian Valley, perhaps more important of these causes I conceive to be the pulse-like inland transmission of oceanic thrusting of largely ex-

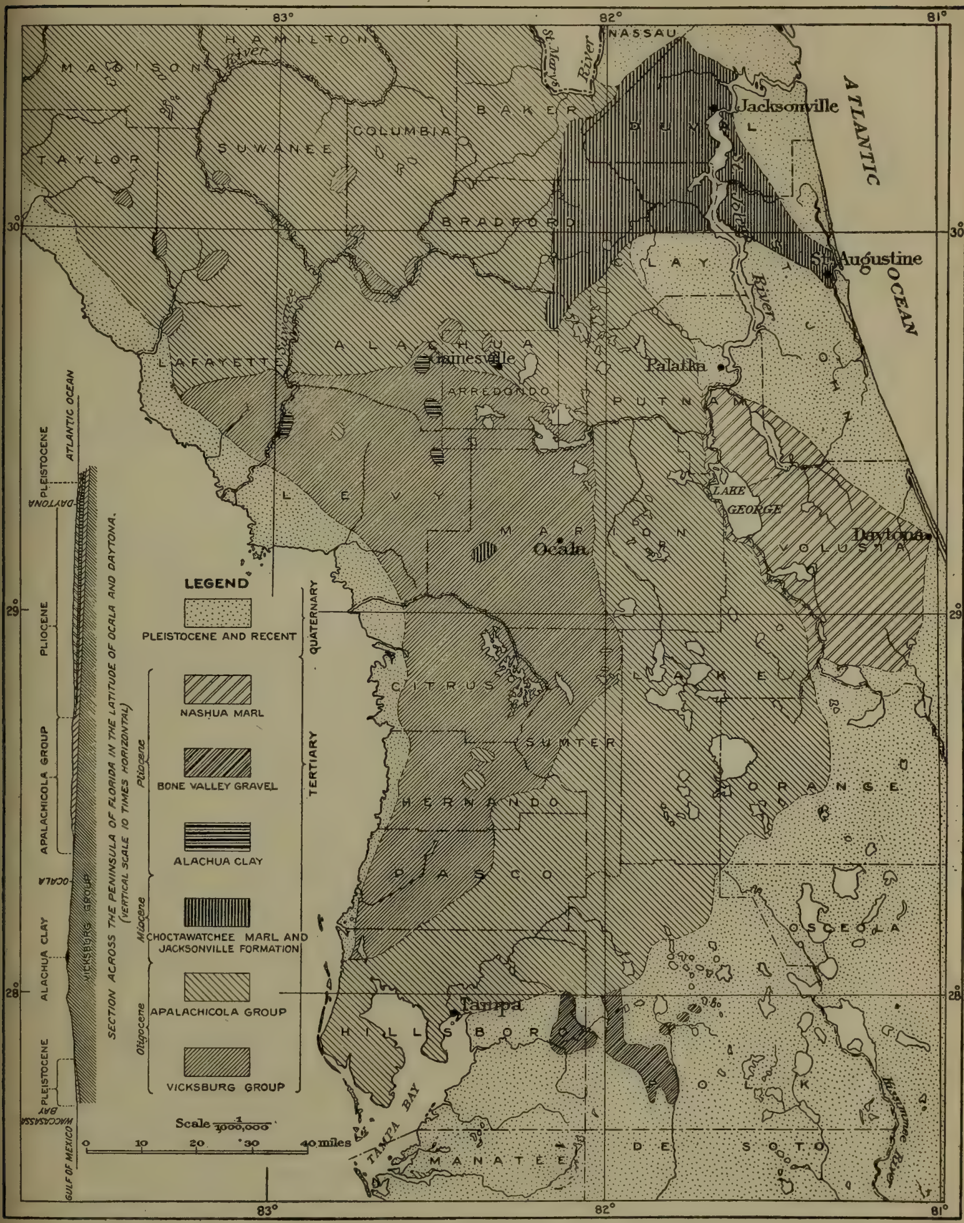


FIGURE 13.—*Geologic Map of North-Central Part of Florida*

Suggesting oscillation of the Ocala dome. From map published by Florida State Geological Survey, 1909

pended intensity. The second cause, alternating with the first, is thought to be the seaward pressure produced in the process of "continental creep" suggested by Chamberlin and Salisbury. Both would result in accentuation of the interior warps or domes, and in either process the greater arching would occur on the far side. This side then would tend to elevation, while the near side, on the contrary, would be relatively depressed and the more likely to be submerged on the next advance of the waters. (See figure 14.) Loading may have been a contributory cause of the more general elevations. (See following note on faulting.)

That sedimentary loading did not cause the differential vertical movements of the median areas of uplift that are referred to under the term

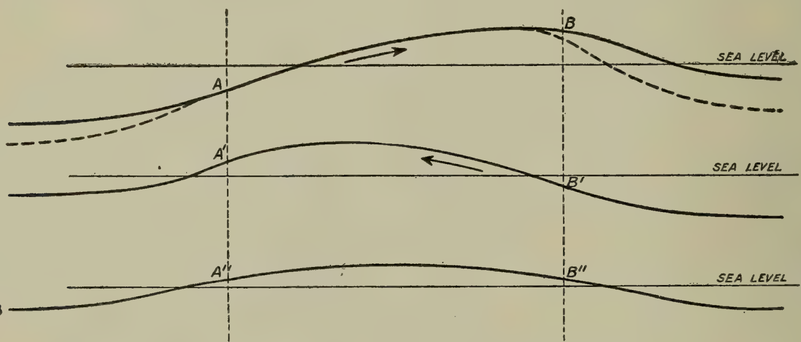


FIGURE 14.—*Diagram illustrating Tilting*

The diagram illustrates "tilting" of interior areas of uplift (for example, the Cincinnati dome), and the causes of the alternate overlap and retreat of the sea on their opposite sides. Arrows indicate direction of pressure. The letters A, A′, A″, B, B′ and B″ mark the same points in the three stages.

"local oscillations" is proved by the fact that the side which received the load in one stage is often the one which was emerged in the next. Obviously, if loading had been the controlling factor in the local vertical movement, then the submerged side would have continued to subside and thus have acquired a further load in the next succeeding advance of the waters. In fact, however, in the cases described, directly the opposite of what should be expected under loading occurred repeatedly. Sedimentary loading is thought to be a dominant factor among the immediate causes of local or general subsidence only in the median parts of great synclinal thoughs or depressions. It seems to have been but rarely, if ever, effective in the way of dragging down the immediate flanks of inland domes. On the contrary, loading is more likely to induce accentuation of slope with relative elevation of the near shore land than subsidence.

Note respecting normal faulting.—Normal faulting constitutes one of the most striking and convincing proofs of differential vertical dis-

placements of adjoining segments of the earth's crust. As these phenomena have, as a rule, no direct bearing on stratigraphic classification, an extended discussion of the subject would be out of place here. However, there is one rather common type of normal faulting that is often found in areas of sedimentary overlaps and which, in the matter of location of the fault-plane, is thought to be connected with sediment loading, namely, faults of the type referred to are very commonly found short distances off the shores of old embayments. Good examples are seen along the overlapping edges of the Paleozoic formations in central Texas, on the flanks of Ozarkia, and on the west side of the valley of Lake Champlain. They occur also, though less typically developed, on the flanks of the Cincinnati, Nashville, and Wisconsin domes. The displacement in none of these cases exceeds 300 or 400 feet and as a rule is less than 200 feet. Where the throw is small great care is sometimes required

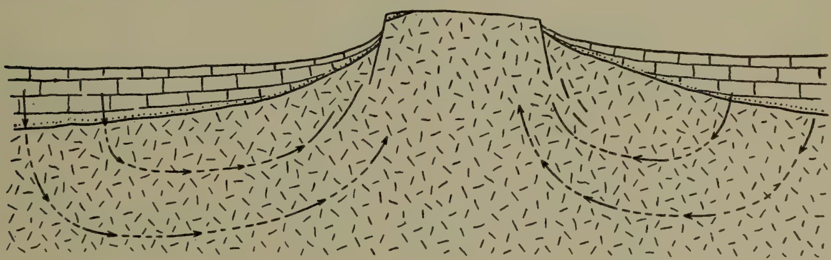


FIGURE 15.—*Diagram illustrating Hypothesis of Origin and Location of normal Faults thought to have been caused by Relief from Stresses which developed through loading of negative Areas.*

to distinguish the fault from the edge of the stratigraphic overlap. The upthrow in these faults is always on the land side of the embayments. This fact has suggested the following hypothesis concerning their origin. The additional load of accumulating sediments in the synclinal embayments, hence in areas already relatively dense and consequently of negative tendency, disturbed the isostatic equilibrium in the region, and caused spreading and flow of deep-seated matter toward the anticlinal areas which are of less density and tend usually to move in a positive direction. Under the circumstances fracture of the thinning crust, resulting in normal faulting, is likely to occur near the margin of the protecting sheets of overlapping sediments. Strictly, the movements as conceived do not contemplate tension, which is commonly assumed to be a prerequisite in the process of normal faulting. There is some expansion of the surface, but the excess is accounted for in the general doming of the areas adjacent to the fault. The upthrow on the landward side of the fault being

occasioned by the relief thereby afforded to the lateral creep of the deep-seated rocks which has been transmitted from the overloaded and hence compressed basement of the synclinal area, the primary cause of these faults may after all be ascribed to compression. Besides, since the upthrusted block or area is one of relative weakness, naturally tending to positive movement under lateral stress, it seems probable that suboceanic spreading and continental creep contributed largely and in a similar manner to the effectiveness of the displacement.

Essentially the same principle may have operated in a folded area like the Appalachian Valley, in which the sediment-loaded troughs sank by gravitation and in which the planes of the resulting normal faults, by rotation in the process of folding, finally assumed attitudes favoring overthrusting.

HORIZONTAL MOVEMENTS DUE TO COMPRESSIVE FORCES

Discussion.—Horizontal movements due to shrinkage[40] of the lithosphere may be assumed to have occurred even in the earliest geologic periods. Judging from the prevalence of folding in all Archean and Proterozoic rocks, it seems likely that such movements were then more nearly equal in vigor in all parts of the surface than in subsequent eras. Suess states this probability very definitely when he says "the folding force was once active over the whole world, but is restricted at present to particular regions."[41] It might be suggested that during Archean ages the oceanic basins were not yet definitely outlined and that the waters covered the entire globe; hence, that contraction effects were then rather general in distribution. On the same and similar grounds may we not reasonably infer that, as the rigidity of the earth increased and the waters were gathered into the continually deepening hollows that are now represented by our oceanic basins, the notable effects of shrinkage became more confined in areal extent and on the whole proportionally less?

From the beginning of the Cambrian to well into the Mesozoic folding of the continental parts of the crust was almost entirely confined to marginal tracts, advancing farther inland only in later periods. A

[40] The term "shrinkage" as employed here and elsewhere in this paper refers to movements resulting in horizontal shortening of segments of the earth's surface, as is indicated by the folding and overthrusting of stratified deposits, the tangential movements of heavily loaded sheets of crystalline rocks, and the piling up of prisms of relatively superficial masses of igneous or unstratified crystalline rocks, all in obedience to lateral pressure. According to the theories of Hayford, Chamberlin, and Willis, such shortening may occur without body shrinkage of the earth. Floating of the crust toward the equator may have helped greatly in many cases.

[41] Suess: Face of the earth, vol. 3, p. 4.

striking fact is that by far the most of these orogenic movements occurred in the equatorial and temperate zones. Indeed, excepting Seward Peninsula of Alaska, no folding of consequence has been reported in lands bordering the Arctic. These facts doubtless are significant in their bearing on the forces which have either separately or conjointly operated in producing the present structural inequalities of the surface of the lithosphere.

Inland migration of Appalachian belts of folding.—During the Paleozoic it is thought that in the Eastern and Southern States excessive folding was confined to the Piedmont and Coastal Plain areas lying between the Appalachian Valley troughs and the north middle Atlantic basin and between the similar Ouachita troughs in Arkansas and Oklahoma and the deeps of the Gulf of Mexico. The thrusts then affected these weak border lands directly, while the broad synclinal areas to the west and north of their inner margins were subjected to comparatively gentle, irregular, but essentially parallel warping. It is this periodic warping that caused the valley oscillations described on pages 321-329, 412-415, and 543-544. To a certain extent it may be responsible also for the tilting of the more inland uplifts.

As time went on the geographic zone of excessive folding and overthrusting traveled inland. Sometime about the middle of the Mesozoic it had reached and passed the inner edge of the bordering lands (Taconia, Appalachia, and Llano) and thereafter warping in the Appalachian and other geographically corresponding synclinoria was superseded by active folding and overthrusting. This supposition is based primarily on the fact that while the late Ordovician shale deposits occupying an old trough on the Piedmont plateau in Virginia are sharply folded and metamorphosed, the similarly located Triassic deposits are but gently folded and comparatively little changed. In seeking an explanation of this difference the first that suggested itself was that the much longer time from the present to the close of the Ordovician might sufficiently account for the greater folding of the older shales. But this suggestion introduced a train of others beginning with a doubt concerning the prevailing view that active shrinkage movements since the beginning of the Paleozoic were confined to three or four periods, namely, at the close of the Pennsylvania, close of the Mesozoic and in the late Tertiary. These are called the mountain-making periods of the first order, the orogenic movements at the close of the Ordovician being rather generally regarded as of lesser importance. (See also page 573.)

Relative importance of periods of folding.—The prevailing classification of continental shrinkage movements is not entirely satisfactory. It seems to me that orogenic movements occurred frequently in geologic times and that the three periods usually set apart as of exceptional importance are probably no more so than others now ranked as inferior or quite disregarded.[42] Perhaps the supposed important movements are exceptional chiefly because their effects were concentrated in areas now readily accessible. Other periods of orogenic movement of similar rank, whose record is but obscurely indicated on the land surfaces now accessible to the investigator, may yet yield to satisfactory demonstration.

The suggested inland migration of the belt of greatest shrinkage leads to the further suggestion that the occasional early and middle Paleozoic mountains of Appalachia were located near the eastern shore of this large land, hence far away from the Appalachian Valley troughs; and on that account alone it is unlikely that they contributed very abundantly to the filling of these inland seaways. Besides, it is known that during the Ordovician a wide median part of Appalachia was depressed and submerged by waters that at times, at least, had no direct connection with the valley troughs. Mountains to the east of this median depression, therefore, could not supply clastic material to the Appalachian Valley; and, obviously, the deposits in the latter give a clue to the character of only the western part of Appalachia and not of its eastern part. The latter, then, may have been strongly elevated at times when only a moderate orogenic movement is indicated by the deposits in the Appalachian Valley. The closing ages of the Ordovician are thought to have been of such a time.

Importance of movements at close of Ordovician.—The late Ordovician disturbances probably were the first of great consequence following the early Cambrian, and that they were of exceptional importance is indicated (1) by the extraordinary extent of emergence prevailing at that time, and (2) by the highly clastic character of the deposits of this age in the middle and northern parts of the Appalachian troughs. Northwardly increasing elevation of western Appalachia is suggested by the

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[42] A very suggestive paper entitled Paleozoic overlaps in Virginia was published by M. R. Campbell in 1894 (Bull. Geol. Soc. America, vol. 5, pp. 171-190). Following the presentation of evidence showing folding in the Appalachian Valley during several Paleozoic ages, he concludes the paper with this significant statement: "Lastly, the post-Carboniferous period of folding has long been considered as the only one and accountable for all of the folding of the Appalachian type that exists in this part of the continent. It now seems as though this was no more important than many which preceded it, and that, in fact, the deformation has been practically continuous since early Paleozoic times."

distribution of these clastics; and strongly eroding streams, rising in unusually elevated Canadian highlands, probably flowed southward across New York and Pennsylvania. Decided warping of the Appalachian Valley and of the more interior areas are credited to this time. Warping or gentle folding, involving earlier Ordovician slates in central Virginia, probably occurred also in the median depression of Appalachia, while stronger folding is shown in eastern New York and the New England States. (See also under Gradational criteria, page 468.) It is to be added, further, that the significance of the great emergence at this time is much increased if we grant the idea of rhythm in occurrence and volume of diastrophic phenomena, because it intervened between the two periods in which the average altitude of the continent was less and the submergences greater than in any other period.

The geographic conditions during the transition from the Ordovician to the Silurian differ in an important feature from all the pre-Pennsylvanian intersystemic stages; namely, in that the earliest marine deposits (Richmondian) of the succeeding period do not occur in the Appalachian troughs but are found in the broad median area of the continent and on its outer border (Anticosti). Indeed, the Silurian is the only Paleozoic period that is not more completely represented by deposits in the Appalachian region than in the Mississippi and Ohio valleys. From all these facts it is clear that in the closing Ordovician and early Silurian stages the whole Appalachian region was considerably elevated and the middle and eastern parts of Appalachia itself most probably subjected to profound orogenic movements. Really comparable conditions occurred here in the Paleozoic only at the close of the Tennessean and in the early Pennsylvanian, with this difference, that the western, rather than the eastern part of Appalachia and the northern part of Llano were greatly elevated, and in the course of their erosion supplied enormous amounts of clastic material now included in the great Pottsvillian formations in the Appalachian and Ouachita troughs. Both of these periods of folding deserve high rank in the classification of orogenic movements.

As to the movements that crumpled the deposits in the Appalachian Valley and that are usually credited with having given birth to the Appalachian Mountains, the date of their occurrence is fairly open to question. It is a long time since geologists have agreed that these movements began late in the Pennsylvanian and were probably completed before or early in the Triassic; and this view is almost universally accepted today. It is with no small degree of trepidation, therefore, that I request reconsideration of the facts on which it is founded. Movements doubtless

occurred at the close of the Pennsylvanian, but I can not see that they were any more important than those in late Devonian or those in late Silurian time. I certainly fail to see any sufficient reason for saying that the Appalachian Mountains were "born" at that time or that the valley rocks were folded then and not before or after. The evidence of repeated pre-Pennsylvanian warping and folding in southeastern North America is so convincing that it seems a waste of opportunity to further discuss it. And that the late Mesozoic and subsequent movements which warped and faulted the Triassic rocks in Virginia, Pennsylvania, and New Jersey may at the same time have expended their energies chiefly in close folding the southern and middle parts of the Appalachian Valley is, to say the least, not an unreasonable hypothesis. But certainly the present result was not all accomplished in any single period. On the contrary land shrinkage movements seem to have prominently exerted themselves in the Appalachian region at frequent intervals throughout geologic time.

Twenty years ago Walcott[43] pointed out that great downwarps or troughs were developed near the eastern and western borders of the North American continent prior to the beginning of the Cambrian; and more recently Ulrich and Schuchert[44] have shown that the more important overthrust faults in the Appalachian Valley began as subparallel folds that had attained sufficient magnitude already in Eopaleozoic ages to divide this great tract into distinct marine troughs. That some of these earlier barrier folds locally attained considerable altitude and suffered great erosion is shown, as on the Rome barrier in the vicinity of Birmingham, Alabama, by the removal of 1,000 to 4,000 feet of Knox dolomite before the eroded surface was covered and preserved by an early Ordovician deposit. Whether the Rome barrier was reduced to baselevel at this time near Birmingham has not been determined. However, it seems doubtful from the fact that some 15 miles northeast, at Foster Mountain, Stones River and Mohawkian limestones, nearly 700 feet in thickness, were laid down in a narrow embayment scooped out of the Knox dolomite.

The remains of the Foster Mountain embayment are preserved in a manner so satisfactory as to leave no question regarding the topography of the immediate region at the time of its occupancy by a small arm of the Ordovician sea. Thick banks of coarse chert conglomerate (Attalla conglomerate) lined the shores, but in the space of a few hundred feet these pass into calcareous shale and this a short distance farther out into pure limestone. Occasionally a thin bed of small-pebbled conglomerate is

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[43] C. D. Walcott: Bull. U. S. Geological Survey, No. 81, 1891, pp. 363-369.

[44] E. O. Ulrich and Charles Schuchert: Paleozoic seas and barriers in eastern North America. New York State Museum, Bull. 52, 1902, pp. 633-663.

found wedged in between the limestones, suggesting that at intervals the shore conglomerate spread entirely across the bay. The larger accumulations of shore conglomerate are confined to the eastern side of the bay, from which it is inferred that the land was both steeper and higher on this side. Corroboration of this view is found in the fact that the sediments as well as the faunas inhabiting the bay are of types characterizing the interior continental basins and not at all like those found to the east of the Rome barrier. (See figure 17 E, page 450.)

Suggestion concerning cause of inland migration of belt of active folding.—The accompanying crude sketches, representing generalized and vertically much exaggerated theoretic cross-sections of Appalachia at important stages in its geologic history, will give a clearer idea of what is meant by inland migration of the belt of folding and of a possible cause than can be gained from words alone. Section 1 shows the supposed relief of Appalachia at the beginning of Cambrian deposition in the Appalachian Valley. Section 2 represents the same in middle Ordovician time. The valley has been gently folded into several shallow troughs, all of which have received varying amounts of marine sediment. Appalachia has a median submerged area; its western part is nearly peneplaned and in course of elevation without folding, its eastern part considerably elevated and folded and limited on the east by an assumed fault-scarp. In section 3, representing an early Silurian condition, the whole region is above sealevel, the Appalachian Valley is receiving some land deposit, the displacement at the marginal fault has been increased, and the zone of active folding has moved farther inland. Section 4 shows the result attained at the beginning and to the close of the Pottsville. The throw of the fault at the edge of the continental shelf has been greatly increased, the Atlantic thrust affects deeper levels, and the deeper shear planes emerge farther inland, causing folding in the median and western parts of Appalachia. The erosion of the latter resulted in land deposits of great thickness in the Appalachian Valley. Peneplanation of Appalachia continued through the remainder of Pennsylvanian time and probably to the close of the Triassic. In the latter age comparatively slight elevation of the western part and relative depression of the median area afforded conditions favoring deposition of the Newark series in the latter. In section 5, representing a subsequent, middle to late Mesozoic, stage, the process has advanced another step, the movement on the new, deeper thrust planes, emerging still farther inland, now being chiefly expended in the folding of the middle and southern Appalachian Valley troughs. The overlying oblique planes ride on the lower planes

which directly transmit the thrust. Section 6 shows the stage supposed to have been reached at the close of the Tertiary, before which time it is thought the movements locally effected complete burial of certain Ap-

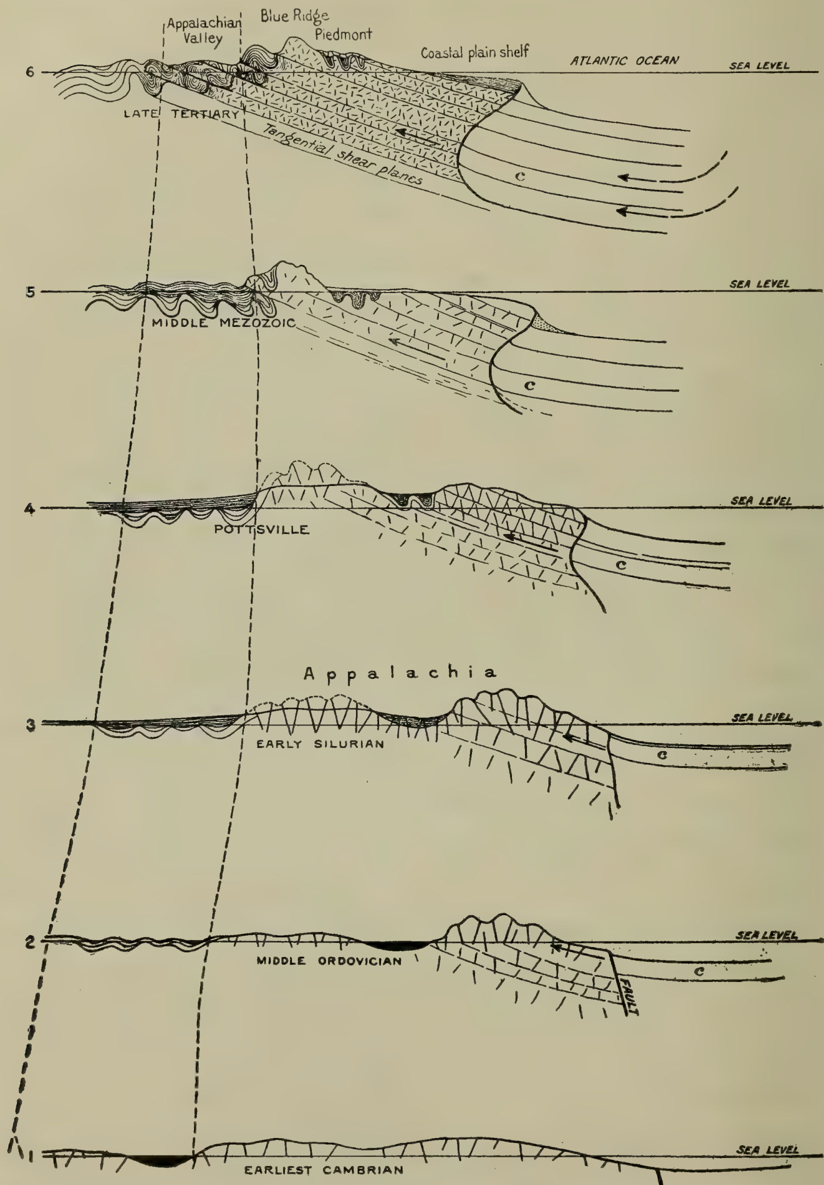

Figure 16.—*Inland Migration of Belts of Folding in Southeastern North America*

palachian troughs by overthrusting of deposits of originally more eastern basins. Such complicated and excessive overthrusting seems to have occurred in southeastern Tennessee and northwestern Georgia, where the deposits of the Athens trough are in contact with those of the Clinton trough. As here outlined the structural history of the Appalachian region appears to be essentially similar to that ascribed to the Alps by the most advanced European geologists.

The principles and processes involved in the above-suggested hypothesis have been discussed by many writers, notably Hayford, Hecker, and Chamberlin and Salisbury. They are essentially the same as those at the basis of Willis's "theory of continental structure."[45] Following Hayford, he regards the lithosphere as heterogeneous in constitution—that is, as "composed of lighter and heavier bodies," the former (positive areas) tending to rise, the latter (negative areas) to sink. These differences in density are postulated as original differences. The oceanic basins being regarded as permanently sunken areas, they are naturally assumed to comprise bodies of maximum density, while the continental areas which have been oftenest or longest land are those of minimum density. The important feature in this connection is the probable fact that the areas of relative density exert a lateral pressure on the lighter areas, and consequently that the continents have been narrowed by compression originating beneath the surrounding oceans. "The pressures are attributed to deep-seated *suboceanic spread*" and their mechanical effects "are seen in numerous shearing planes on which, under appropriate stress, the masses rose as on an inclined plane."

The modified hypothesis as above outlined accepts the essential principle of Willis's theory, namely, "suboceanic spread" due to deficiency of density in the positive continental masses, and differs chiefly in that it adds, in order to explain conditions not contemplated by Willis, the idea of faulting at the margin of the continental shelf. The displacement of this fault is supposed to be increased periodically, and as deeper and deeper zones are affected in the progress of the suboceanic spread new tangential planes of movement are formed in the adjacent positive areas; and the successively lower planes emerge farther and farther inland.

Whatever the relative altitudes of the eastern and western parts of Appalachia may have been in Paleozoic ages, two facts give decisive evidence in favor of the greater elevation being in the west during the Newark and Cretaceous periods. The first of these is the development of

[45] Bull. Geological Society of America, vol. 18, 1907, pp. 389-412.

conglomerates in the Newark deposits between New York and Virginia only on their western margins; the second is the overlap of the eastern border of the Newark in New Jersey by Cretaceous sediments, showing that at this time the eastern barrier was very low and in places submerged.

The movements recorded in the Paleozoic eastern border lands of North America south of the Saint Lawrence evidently were not uniform in the two parts separated by the latitude of New York City. In the New England part vulcanism played an important role. Not so much in the south, where, moreover, there is little reason to believe that Paleozoic sediments occur beneath the Mesozoic and Tertiary deposits of the Coastal Plain like those found in the eastern part of New England. Following the general strike of the rocks, folding would seem to have taken place in the strip just east of the "great fault" (Saint Lawrence and Hudson rivers) at an earlier date than in the apparently corresponding bend south of New York. Probably, as has been suggested by Willis and others, New England exposes marginal parts of the continent, the structural equivalents of which are submerged beneath the waters of the Atlantic or covered by the blanket of later deposits forming the southern Coastal Plain. However, the more or less metamorphosed character of the rocks north of New York City and east of the great fault, and certain extraordinary features concerning the distribution of particular faunas and sediments in this area, suggest a supplementary explanation, namely, if the evidence in hand were fully discussed, I believe it might be shown with a fair degree of plausibility that overthrusting has progressed to such an extent in western New England, eastern New York, and southern Quebec that bands corresponding in original geographic position to the Ordovician slates in east central Virginia have been brought into juxtaposition with bands corresponding in original strike to the Appalachian Valley troughs.

Overthrust troughs in eastern New York and western New England.—I believe that in the area between the Adirondacks and the Hudson River on the west and the Green Mountains and Berkshire Hills on the east the outcrops of varying types of rock represent deposits in originally distinct troughs that have since been thrust westward over each other. Irregularities in thrusting, and in subsequent as well as concomitant erosion, are responsible for the present outcrops of the buried troughs. The evidence on which this belief in distinct troughs is based is threefold in character, faunal, lithologic, and structural. The first is shown by differences in fossil contents, the deposits in the Chazy basin just to the east of the Adirondack mass being filled with associations of organic

remains that can not be recognized in the limestone and shale deposits farther east, while differences are noted again in comparing the faunas of the latter. The second is expressed, first, by peculiarities in the succession of the various general types of sediments, which on comparing local sections may be arranged into four groups, and, second, by the degree of metamorphism to which the deposits have been subjected. The third component of the evidence is the physical proof of excessive folding and overthrusting shown by the structure of the various rock masses.

Going eastward from the Adirondack areas of Precambrian crystallines, we see, first, the Chazy basin sediments in the Champlain Valley. The stratigraphic sequence in this basin is Potsdam sandstone, Little Falls dolomite, three Beekmantown limestone formations, three Chazyan limestone formations, Lowville and later limestones of the Black River group, Jacksonburg limestone, and, finally, Martinsburg shale. Most of these formations are filled with fossils, segregated into distinct associations, by which the formations or zones of which they are characteristic are recognized in the Appalachian Valley to the south of New York, as well as in different parts of the Champlain Valley.

East of the Chazy basin is the Levis channel. In eastern New York its most characteristic deposits are (1) shales and shaly, often conglomeratic, limestones, constituting the Canadian (Levis shale) part of the sediments in this trough and characterized by the *Dictyonema flabelliforme*, *Tetragraptus*, and *Didymograptus bifidus* faunas, and (2) the Normanskill and Magog shales, containing later well defined Ordovician graptolite faunas. In Canada it may be that other formations (Lauzon and Sillery) were laid down in this channel, but in view of the fact that these formations are separated from the graptolite-bearing shales by fault planes, it seems advisable provisionally to exclude them from the Levis channel. The lower Cambrian deposits at Saint Albans and Georgia, in northwestern Vermont, are more likely to belong here beneath the Levis. As to the typical deposits of this channel, they have been recognized at widely separated intervals by graptolites characterizing one or another of the zones all the way from Jutland, New Jersey, to Newfoundland. In the south a similar channel containing the Normanskill fauna is indicated at intervals along the eastern border of the Appalachian Valley from northern Virginia to central Alabama. The zone containing this graptolite fauna in the south is included in the Athens shale of east Tennessee.

The third trough east of the Adirondacks and Hudson River contains the marble formation in western Vermont and succeeding limestone and

shale formations. Possibly the lower Cambrian deposits thought to belong in a fourth trough in fact preceded the marbles in the third basin. However, judging from data now available, it has seemed preferable to assign them to distinct troughs. As a possible compromise between the two views, it may be suggested that the lower Cambrian deposits are confined to the supposed fourth trough, but that the much younger marbles, limestones, and shales are common to both the third and fourth troughs. Regarding the age of the Vermont white marble formation, it must be confessed that the evidence is not positive. By inference, based on stratigraphic position and probable movements controlling location and character of deposits, the age of the marble is provisionally determined as middle Canadian—that is, as approximately corresponding to Division D of Brainard and Seely's Champlain Valley "Calciferous." The limestone overlying the marble formation contains some fossils, but their age relations are not exactly determined. There is little doubt, however, that this overlying limestone represents an age following the close of the Stones River and preceding the Trenton, hence as correlating with some part or parts of the Blount and Black River groups. The shale formation which closes the sedimentary record in this trough is referred with considerable confidence to the Martinsburg shale, a formation that, like the correlatives of the underlying limestone and marble formations, is widely distributed in and to the east of the Appalachian Valley proper. The fine-grained white and pink marbles which outcrop at intervals from beneath overthrust formations to the east of the valley from Vermont to Alabama seem all to be, according to present evidence, essentially of the same (middle Canadian) age. At any rate, I have met with no evidence positively opposed to this view.

As already intimated, the sediments in the supposed fourth trough are the quartzites, shales, and limestones of lower Cambrian age now found in Washington County and other parts of New York east of the Hudson. Similar deposits containing a comparable if not the same Olenellus fauna occur in the mountainous eastern rim of the Appalachian Valley from northern New Jersey to Alabama. The strikingly uniform character of these deposits long ago suggested the now generally accepted view that in early Cambrian times the sea invaded the inland surface of eastern America only along a narrow down-warped band, stretching southward from Canada to central or southern Alabama. The land to the east of this trough probably was not very high, but was covered with a deep, well decomposed regolith (rock mantle), much of which was swept into the deepening inland trough. It is doubtful whether at this time the submergence of the trough extended down the Saint Lawrence to New-

foundland, but lateral extensions across local depressions in the land to the east, permitting free communication with the Atlantic sea, are thought to be more likely.

Finally, a fifth trough, or rather set of troughs, is thought to be indicated by the highly metamorphosed Paleozoics found to the east of the lower Cambrian outcrops. Theoretically, none of these should be older than middle Cambrian, but many later ages up to the Jurassic might be represented. Most probably, however, the sequence was frequently interrupted. Local masses of sparingly fossiliferous slates and shales in southwestern Vermont and eastern New York north of Albany do not fit in with any of the deposits above assigned to the several troughs. Dale[46] referred some of these slates to the Cambrian, but a recent study of the fossils shows them to be of some Canadian age. Where I have seen them in Vermont (especially near Sudbury) they rest unconformably on the eroded folds of the marble, limestone, and shale sequence characterizing the third trough.

If, as I believe, these unassigned slates and shales really belong to the deposits of the fifth trough, it will be necessary to devise some plausible explanation of how they came into their present position. Perhaps the following may be so considered: The shales of the eastern belts were first folded and thrust westward by "suboceanic spread." The latter, continuing and affecting deeper zones, then folded and pushed the deposits in the lower Cambrian (fourth) trough over the edge of the Rutland marble basin, the more "competent" Cambrian beds carrying with them their previously acquired load of slates of the fifth trough. With further folding and thrusting and removal of the advance edge of the overthrusting lower Cambrian by erosion, it is readily conceivable how the load of slate riding in a syncline might finally get into a position favoring a gravitational slide into the limestone valleys of the third trough. Indeed, in areas of less erosion and hence apparently greater overthrusting, as in Washington county, and probably farther south in New York, slates of the fifth trough might have come into contact with the shales of the Levis channel.

If these supposed great overthrusts are due chiefly to suboceanic spread, and if the idea of inland migration of the zone of active folding is correct, then we have in the inland riding of the relatively shallow older shear planes on the deeper inclined planes of the newer thrusts[47]

[46] T. Nelson Dale: The slate belt of eastern New York and western Vermont. U. S. Geological Survey, 19th Ann. Rept., Part III, 1899, pp. 153-300.

[47] In speaking of the superficial older sheets as riding on the inland moving new plane I do not mean to say that the emerged parts of the former are no longer subject to independent movement. On the contrary, I believe that the older sheets not only lagged

an explanation of the probable fact that the New England coast represents a more easterly part of the Paleozoic continent than is emerged in the south. Why overthrusting was carried to a greater extreme in eastern New York than in, say, Virginia may be due to that ancient peninsular projection of the Canadian shield—Adirondackia—against which deeply rooted buttress the sedimentary rocks were piled. As explained on page 565, the Catskill mass of Devonian rocks probably also caused extraordinary overthrusting of Eopaleozoic deposits to the east of it.

Relation of lateral creep of continental platform to suboceanic spreading.—The theory of lateral spreading of the continental platforms suggested by Chamberlin and Salisbury[48] is based on the apparently reasonable supposition "that during profound body deformations the continental segments may be pressed up, in portions at least, beyond the plane of equilibrium, and that during the period of quiescence that follows they tend to settle back to the equilibrium plane." In discussing the proposition the authors state "that continental spreading or creeping will, within the limits of its operation, diminish the capacity of the ocean basins, and so tend to cause the waters to overflow the lands." Further, they say "such a movement would be unsymmetrically distributed, and the result would be manifested in slow, quiet warping."

Confined to the surface of the continents within the marginal areas which have been more especially affected by "suboceanic spreading" (see page 435), the process of continental creep may well have been an important factor in the production of the gentle warpings and differential tiltings of the median areas of frequent uplift described on preceding pages. As stated by Chamberlin and Salisbury, the force of gravity back of the tendency to "creep" is "perpetually in readiness to act." At the same time the forces causing suboceanic spreading are no less continuous in their operation. The two processes then are forever at war, the issue wavering between them. The latter at times forces the whole continent out of the water, the former ever tends to depress the median portions. Either movement would naturally result in gentle warping and buckling of the median areas, and the alternating dominance of one and then the other probably would produce results sufficiently

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behind the newer basal sheet, but that they yielded to an inherent gravitational tendency to backsliding. Warping, normal faulting, and locally even considerable folding and slight underthrusting should therefore be expected in the sedimentary rocks that were laid down on marginal areas after the belt of folding had migrated inland beyond their location. Retreat movement of this kind is suggested by the folded Pennsylvanian deposits in the Narragansett basin.

[48] Geology, vol. ii, 1907, pp. 131, 233-236.

variable to account for the unequal distribution of sediments which I have ascribed to local differential movements.

The long downwarps prevailing during Paleozoic times in the Appalachian Valley may have originated chiefly in continental spreading, and the same process probably contributed as much as any other cause to their gradual deepening in the course of their depositional loading. Indeed, this seaward creep probably aided greatly in the subsequent stronger folding of these Appalachian troughs—if not by actual outward movement, then at least by its opposition to the oceanic inland thrust. The usual attitude of the Appalachian folds, with their steep westerly and less steep easterly dips, is not opposed to this view, since the force of the outward creep of the continent would expend itself chiefly on the lower part of the fold, while the emergent tendency of the suboceanic spread would affect the upper part of the fold rather than the lower.

Inland transmission of suboceanic thrusts.—Assuming (1) the periodicity of diastrophism, (2) the competence of "suboceanic spreading" to cause landward thrusting of marginal areas of continents, and (3) that seaward "continental creep" is an important factor in the causation of deformative movements, certain conceptions relating to the inland transmission of suboceanic thrusts are suggested. In the first place it seems reasonable to believe that stresses accumulated in the oceanic area until they were strong enough to overcome the resistance offered by continental creep. Before reaching this point, local and perhaps general deepening of the oceanic basins occurred, with the probable if not inevitable result of sea withdrawal from the continents. Obviously, the land movement would manifest itself first in the marginal areas beneath which a tangential thrust or shear-plane (see page 440) would sooner or later be established. Previous to this, as is suggested, for instance, by the great withdrawal of interior continental seas at the close of the Trenton, the continent as a whole may have responded to the deep-seated landward pressure or flowage by general median elevation. As a rule, however, much of this interior doming seems to have been deferred till after the development of the tangential thrust-plane and the decided warping and folding which occurred in the belt at its emergence (see north-south tilting and note on faulting, pages 407 and 433).

Despite the relief afforded by the development of this tangential thrust-plane, horizontal movement in the matter beneath it probably continued. Theoretically, this lower zone should at first have responded a little to the stress of continental spread, but soon the drag in the deeply buried shear zone may have stopped and then reversed the seaward movement

into a landward one resulting in slight continental doming. It is conceivable that between these and perhaps other opposing stresses the median continental areas pulsated back and forth, the balance of movement favoring continental creep, first in increasing, then in decreasing ratio, until such time when sufficient oceanic stress had accumulated to reverse the balance of movement and thus to inaugurate a new cycle. Such an ideally-rhythmic progress of geologic events is, of course, impossible in an earth composed, like ours, of varying elements. But, granting considerable modification by more or less adventitious circumstances, which indeed in the course of geologic ages have become more and more diverse and important, I yet believe that diastrophic movements were governed by a plan not greatly different from the one here briefly outlined. Judged by the diastrophic history of Paleozoic periods in America, it seems a reasonable working hypothesis. Each of these periods, so far as worked out, indicates a preceding, sometimes very long, stage of general emergence, during which baseleveling agencies were active, followed presently by a long stage of oscillating sea advance and then by a shorter stage of oscillating sea withdrawal which finally passed into the next general emergent stage. (See also chapter on displacements of the strandline.)

Structural Criteria

GENERAL DISCUSSION

The structural phenomena which have a more or less direct and correspondingly exact bearing on stratigraphic correlation and taxonomy are those indicating either positive or negative displacements of the strandline. Positive displacements—that is, advance of shorelines—are indicated (1) by progressive overlap of sediments,[49] and (2) by peculiarities in kind and arrangement of the initial deposits. Negative displacements or sea withdrawals are indicated (1) by evidence of shallowing, (2) by imperfections of the sedimentary record, beds or formations of ages elsewhere represented by deposits being absent, (3) by obviously unconformable relations of adjoining beds, and (4) by less clearly manifested evidence of discontinued marine sedimentation and emerged or land conditions. The general aspects of these phenomena, also many examples, are more or less fully discussed in preceding parts of this work.

[49] As used in this work the term "progressive overlap" refers only to the progressively spreading deposits of an advancing sea. "Regressive overlap," on the other hand, is applied only to the areally diminishing deposits left by a retreating sea.

The following remarks, therefore, will be confined so far as practicable to the criteria themselves.

Less definite in their bearing, and of use only in broader correlations, are those phenomena which indicate periods of rejuvenated orogenic activity. Having devoted considerable space in preceding chapters to the discussion of the earth movements which occasioned them, this phase of the subject may be passed without further comment. Moreover, since these periodic activities are chiefly indicated by consequent quickening of erosional processes, and as matter pertaining also to this aspect of the subject is presented in the introductory chapters comprising Part I, it is thought advisable to defer additional consideration of such criteria to a more appropriate succeeding chapter on degradational and lithological criteria.

PROGRESSIVE OVERLAP OF MARINE DEPOSITS

Rate of progress.—The criteria of progressive overlap are primarily such stratigraphic phenomena as indicate landward spreading of successive zones of deposition in an advancing sea. Obviously the rate of progress depends on the relative steepness or gentleness of the slope of the land in course of submergence. If steep the successive stages of the overlap as registered by the landward progression of each layer beyond the next preceding is correspondingly slow and small in horizontal dimensions; if very gentle the younger layer spreads with proportionate rapidity and in extreme cases may extend great distances beyond the limits of the next older stratum. Obviously again in the case of long and relatively narrow troughs the longitudinal progress of the overlap is proportionately much more rapid than the transverse advance. Figures A and C of the accompanying sketches illustrate relatively rapid transgression of overlapping formations, while in D and E, more especially the latter, the overlaps progress much more slowly. The Boone at the top of D is a widely transgressing formation; hence relatively rapid in overlap.

Most of the Cambrian, Ozarkian, Silurian, and early Devonian formations in the several depositional troughs of the Appalachian Valley constitute excellent examples of rapid longitudinal and slow transverse advance of overlapping deposits. Some of these formations, notably a reddish middle Cambrian shale, the Copper Ridge chert, and the typical Clinton, extend northwardly from Alabama and Tennessee to or beyond southern Pennsylvania, while their present distribution in an east and west direction is commonly confined to strips less than 75 miles in width. The Arctic invasions of the relatively flat median areas of the

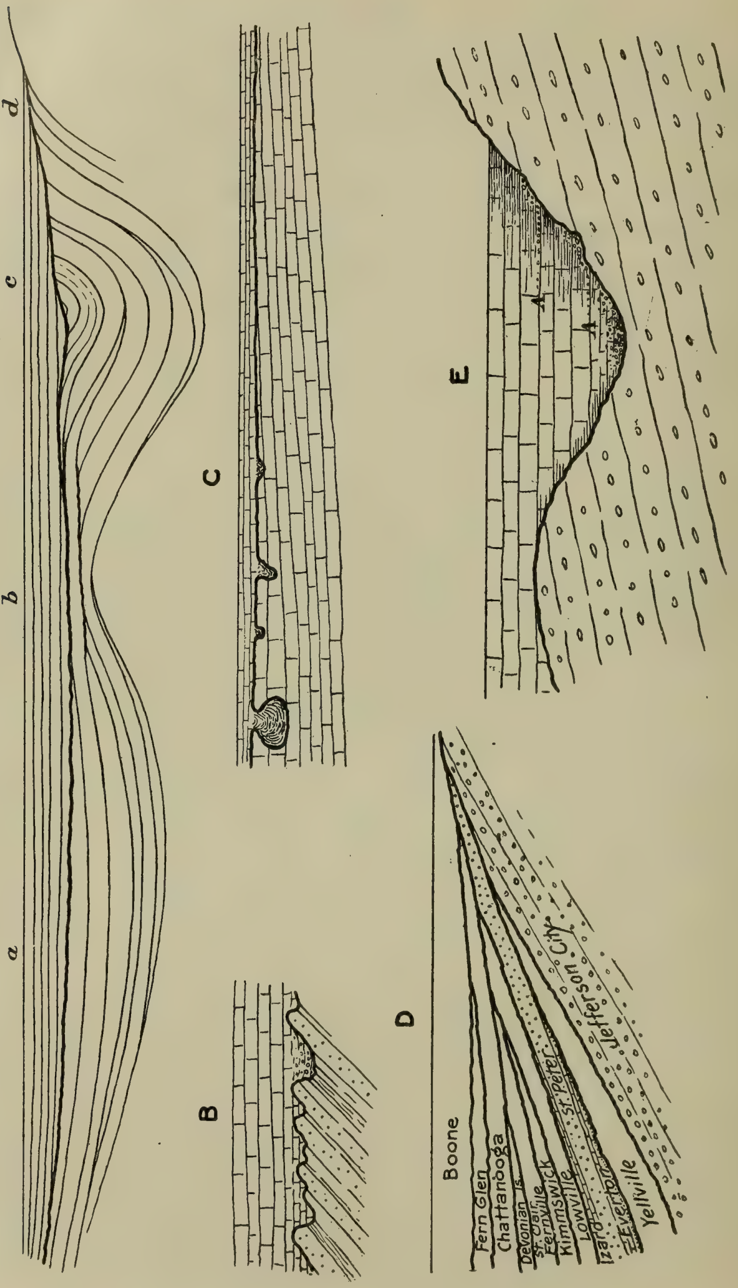

FIGURE 17.—*Diagrams illustrating Overlaps and Unconformities*

A shows a formation transgressing from a broad shallow basin across the eroded edges of beds in a deeper syncline, as, for instance, from the Allegheny basin eastward over an Appalachian Valley trough. The unconformity at the base of this overlapping formation varies greatly from place to place in the angle of divergence of beds on its opposite sides and in the time value of the hiatus. At *c* the structural discordance is much greater than at *a*, *b*, and *d*, though at each of the latter points the hiatus is greater than at *c*.

B shows an "angular" unconformity with a limestone resting on the eroded edges of a tilted sandstone formation. The contact is irregular because of inequality of resistance offered to erosion by the underlying formation, and the depressions may or may not contain accumulations of clastic material. Often they are swept entirely clear of such matter by the advancing sea. An unconformity like this is seen at Rondout, New York, where late Silurian limestone overlaps tilted late Ordovician sandstone.

C shows an unconformity between two limestones, as between the Kimmswick and Fernvale limestones south of Saint Louis, Missouri. In these cases, as shown in the right half of figure, the unconformity is often barely distinguishable from an ordinary bedding plane. At other places, however, the surface of the lower formation is more uneven and occasionally exhibits solution cavities or channels, which are filled with sweepings of the old surface, or even by ordinary marine deposits not seen in adjacent parts of the section.

D illustrates stratigraphic conditions observed on the southern slope of Ozarkia, and shows how the major unconformity on the right, where the Boone rests on the Jefferson City, wedges apart so as to permit the intercalation of numerous other overlapping formations that are intermediate in age and similarly unconformable in their relations to each other. Obviously the time value of the hiatus separating the intercalated wedges is greatly inferior to that of the combined hiatus found toward the summit of the island; but in physical manifestation and structural discordance one may be as clearly defined as another.

E shows a cross-section of the Foster Mountain embayment, north of Birmingham, Alabama. This was excavated in the western slope of the Rome Barrier and subsequently occupied by a small arm of the Ordovician sea coming in from the west. This occurrence is important in proving that considerable relief and consequent surface erosion took place occasionally in the Appalachian Valley as far back as pre-Ordovician times, and in showing (1) that the heavy chert conglomerate was dropped close to the shore, and (2) that the argillaceous near-shore deposit may give way to pure limestone deposition—in this case it does as a rule—in less than half a mile from the shore. Occasionally small chert pebbles were carried much farther out.

North American continent, as noted and explained on pages 407 and 409, effected in perhaps every case extraordinarily rapid extensions of sedimentary planes. Overlap structure in these cases is demonstrable only on the flanks of island domes and peninsular projections included in the general area submerged at such times by northern waters.

General prevalence of overlap structure.—With relatively few exceptions, lithologic or stratigraphic units, whether constituting the whole or merely subordinate divisions of formational units, are bounded below by progressive overlap structure. The exceptions consist almost solely of instances of limestone or shale formations which grade laterally into more clastic, near-shore, delta or fluviatile, deposits. Notable instances of such transitions have been shown to occur in the Devonian of New York by Clarke, Williams, and others who have contributed to our knowledge of the stratigraphy in this State. These cases are typical of a class in which land debris is accumulated in a bay or along a shore, finer sediments being laid down farther out. The Selma chalk band in the southern States which, according to unpublished investigations by L. W. Stephenson, passes at each end into less calcareous deposits, seems to illustrate a different class, namely, deposition around a low blunt peninsula influenced by lateral drainage, so that relatively clastic deposits formed on its sides and calcareous sediments off the rounded extremity.

Though lateral transitions in lithic character have hitherto been supposed to occur very commonly, a critical review of the cases has shown that true transitions of this kind are by no means common. As a rule the presumed lithically changing stratigraphic zones proved to comprise deposits that were not only laid down in physically distinct troughs or basins, but also that their respective beds are not contemporaneous. Faunal studies first suggested and have finally established the proposition of small, disconnected, oscillating continental seas; but, after all, the most convincing and therefore necessary evidence was furnished by stratigraphic overlaps. In the Appalachian Valley, for instance, most of the Eopaleozoic formations were found to be confined to a single or to two adjacent troughs. Other formations spread more widely and are found in three or more basins. In the broader interior basins the stratigraphic record as exposed on the flanks of low uplifts is punctuated at frequent intervals by evidence proving oft-repeated advance and retreat of marine waters.

Owing to overthrusting of the middle and eastern troughs in the Appalachian Valley, the overthrusting being incidental to the excessive folding of the valley rocks (see figure 16, section 6, page 440, and figure 9,

page 414), the eastern edges of their respective formations are as a rule inaccessibly buried. The raised western edges, too, have in most cases been removed by erosion, but several satisfactory remnants are still to be found. Actual, indeed great thinning by westward overlap is shown by the Holston limestone and in a smaller degree by the Ottosee formation in the Ordovician belts next east and west of Loudon and Concord in Tennessee. Similar east-west thinning and final extinction is clearly shown by members of the Chambersburg limestone in southern Pennsylvania. (See description in Part I and figure 3.)

That overlap extinction of stratigraphic units on the sides of the original Appalachian troughs actually occurred is reasonably inferred from the fact that certain formations and faunas are confined to certain troughs. Thus, as shown on the map of Ordovician outcrops in the southern part of the valley (see map opposite page 412), limestone deposits that may be referred to with propriety as the Trenton and Stones River groups are confined to the Clinton and more western bands (see page 293). The intervening Black River group likewise occurs in the western troughs, but differs in spreading farther eastward, being found in considerable development in the Pearisburg trough, the Lowville part, indeed, extending as far eastward as the Knoxville trough. On the other hand, the sediments and faunas of the Lenoir, Tellico, and Ottosee formations are confined to the Knoxville and Athens troughs, while the Athens shale is seen only in the Athens trough. The Holston, finally, is absent in the Athens trough, best developed in the Knoxville trough, and locally overlaps westward into the Clinton and Newman troughs (see also table facing page 544).

Interfingering overlaps.—Exact correlations of such geographically limited formations are always difficult. The faunas often serve only in a broad general way, because they are frequently derived from distinct oceanic basins in which organic evolution progressed along lines peculiar to each. The most valuable aid in determining their age relations is occasioned by differential surface oscillation which permitted interfingering of overlaps from different directions, as, for instance, by alternations of westward transgressions of Atlantic waters into troughs more commonly occupied by invasions from the Gulf of Mexico and *vice versa.* The principle is fully illustrated by examples in a later section (see pages 538 to 568).

The broad differential movements of the continent and the minor oscillation of the interior structural domes described in preceding chapters under the term "tilting" have resulted in similar interfingering overlaps.

These have not only established that such movements actually took place, but their evidence has proved of the highest value in unravelling perplexing problems of correlation. Without such evidence the attempt to prove that the Carter division of the Stones River group does not outcrop on the east side of the Nashville dome, and that beds on that side which seemed to occupy the same stratigraphic position and were in fact correlated with the Carter by Safford are really Lowville, hence younger, might well have failed to convince. But the task lost most of its difficulties when a thin wedge of Lowville was found resting unconformably on the Carter near Nashville; and the correlation became easily convincing when typical magnesian Carter limestone was found at Highbridge, Kentucky, beneath a full Lowville section.

For similar reasons, although strongly suggested by differences in faunal contents, it would have been difficult to prove the alternating transgressions of Arctic, Pacific, and Gulf of Mexico waters, described on pages 367 to 371, if the thin wedges of northern formations had not been found in Kentucky and Tennessee and if it had remained unknown that the Kimmswick limestone passes under southward extensions of lower members of the Galena group in northeastern Missouri. Or, taking another case, to prove that the Maquoketa shale, which closely simulates the Utica in appearance and fauna, is really of middle Richmond age, if we did not know from unequivocal evidence in eastern Missouri and west central Tennessee that it overlies two lower Richmond formations—the Fernvale, and beneath this the Arnheim. Evidence of this nature is simply incontrovertible. In short, no other evidence is so trustworthy in disproving supposed synchrony of deposits which have been correlated chiefly or solely on fossil evidence, or because of apparent likeness in stratigraphic position, as that of stratigraphic overlaps. Nor is any so valuable in narrowing the limit of possible error in correlating disconnected lithologic units that happen to be included between two more widely transgressing formations.

PECULIARITIES OF INITIAL DEPOSITS AT BASE OF OVERLAPPING FORMATIONS

Ordinarily we expect to find a layer consisting wholly or in part of ill-assorted clastic material at and rising with the bottom of an overlapping formation. Sometimes it is a sandstone the grains of which are likely to be rounded; or it is a conglomerate the pebbles of which may have been derived from the immediately underlying rock or from many near to distant sources. Again the basal layer is a mudrock, in one case composed mainly of clay, in another calcareous enough to be called a lime-

stone. As a rule, the material is imperfectly stratified, and often, especially between two limestone formations or between a shale and a limestone, it suggests agglomeration of loose surface matter into mud balls. When the transgression is over an old land area it is often red; occasionally it contains enough of iron to constitute a low-grade ore. At other times yellowish and green patches may be noted, while more rarely there is a suggestion of fossil black soil. In most cases this initial deposit consists mainly of wave-transported regolith, and its principal service is to pave the way for succeeding regular deposition by filling the decomposition and solution hollows in the old land surface now in course of submergence. Obviously, then, the deposit may vary greatly in composition, and it is always irregular in thickness and distribution. At one point it pinches out to a few inches or nothing; at another near by it may thicken to 50 feet or more. Its composition depends largely, and sometimes entirely, upon the character of the rocks exposed in adjacent contributing lands. Sometimes, however, prevailing winds and other climatic conditions that more commonly affect drainage and deposition may introduce relatively foreign constituents in considerable quantities.

The Chattanooga shale formation in Tennessee and in Arkansas and Missouri offers many interesting and instructive illustrations of overlap phenomena, and especially such as concern initial deposits. The features of the Tennessee occurrences have been described in sufficient detail by Hayes and Ulrich.[50] Those observed in Arkansas and Missouri are even more varied. In northern Arkansas the Sylamore sandstone, evidently a beach deposit, presents the prevailing aspect of a sandy basal deposit. This sandstone resembles the much older St. Peter sandstone, and in fact consists chiefly of the more or less cleanly washed soil of areas in which bodies of the St. Peter were then exposed. Though usually less than 2 feet in thickness, the Sylamore expands to much greater thicknesses in places where it fills depressions in the preceding land surface. Very interesting accumulations are found, too, that seem to represent fillings of late Devonian caverns in the underlying Ozarkian dolomites. Even more remarkable are the vertical, subtubular solution channels seen in the quarries near Clarksville, Missouri. These extended completely through a Niagaran dolomite before the Chattanooga submergence reached this point and filled the tubes with wave-swept black land debris.

When little or no coarse material, either native or foreign in derivation, is included in the initial deposits, the lowest bed or beds of the overlapping formation often resemble the underlying rock in composition.

[50] Geol. Atlas U. S., Columbia folio, No. 95.

If the latter is a shale, the first bed of the succeeding formation is likely to be an amorphous or obscurely stratified clay shale. If it is a limestone, then the new bed commonly is a highly calcareous, thin, and irregularly distributed mudrock. The resemblance is greatest when the sea transgresses over a sandstone surface. In such cases, as, for instance, in Arkansas and Missouri, where the Sylamore or some even younger sandstone is occasionally found in contact with the St. Peter or some other sandstone, it may be very difficult to draw the line between the old and the reworked new deposit.

Theoretically the littoral deposits of a sea should be of coarser grain than those laid down at depths beyond the reach of wave action. Strictly speaking, the facts are in essential accord with the theory, but viewed from the side of practical stratigraphy the difference is rather generally of small consequence and often quite negligible. Although a large amount of data respecting near-shore deposition in Paleozoic continental seas is in hand, the space here available permits only the briefest reference to a few. However, fuller references to these and other cases of obscurely indicated littoral deposits will be found in this and preceding chapters.

LITTORAL CONDITIONS RECORDED BY INITIAL DEPOSITS

Accepting as an established fact that nearly all diastrophically determined formations have an overlapping structure— the exceptions being formations based solely on lithologic differences—it follows that the basal layers of each constitute a continuous local record of littoral conditions during the time consumed in the respective transgressions of the sea. In each exposure of such basal layers we see, therefore, a representation of the littoral deposits of the sea at a particular time and place. Comparative studies of stratigraphic units carried on under this conception show that in the case of limestone formations the littoral deposits are but seldom, and at that only locally, conspicuously more arenaceous than the deeper water sediments. The relatively common exceptions are limestone formations, like the Boone in northern Arkansas, which transgressed old land surfaces, and in such situations begin with a few inches of sandstone. Despite the prevailing contrary conception, unquestionable major exceptions are few indeed. The best that comes to mind at this moment is the Joachim, a magnesian limestone in Arkansas, Missouri, and western Illinois that is regarded as having been deposited in the wake of the northwardly advancing St. Peter sea.

In a great majority of the limestone cases there is no sign of quartz sand at the base; and when such material is present it is usually confined

to a layer less than a foot in thickness. Further, as suggested above, this layer owes its existence chiefly to the fact that the overlap extends to or across areas exposing older sandstone formations. For this reason a thin basal sandstone is a rather common feature of formations developed on the flanks of Ozarkia, whose broad dome of Eopaleozoic rocks comprises several important sandstone formations. On the Cincinnati and Nashville domes, however, where old arenaceous deposits are almost wanting, overlaps are but seldom indicated by quartzose initial deposits. The principal, not to say the only, exception is the Chattanooga shale, and this probably derived its basal sandstone from Ozarkia.

As a rule, the percentage of argillaceous matter in limestone formations increases toward the shore, but even this change is generally not very conspicuous. Indeed, it is with considerable surprise that we noted the small thickness of impure reddish limestone that separates in every way typical Pamelia limestone in New York and pure Lowville limestone in the vicinity of Kingston, Ontario, from the pre-Cambrian floor. Surprise was felt again when, after a long search near Theresa, New York, the contact between the base of the Pamelia (upper Stones River) and the top of the Theresa (earliest Canadian) finally was located, and nothing found, save an inch or two of fine conglomerate, to indicate that the hiatus is of sufficient magnitude to represent deposition of 5,000 feet of dolomite and limestone in central Pennsylvania. Also, again in New York, when we found no conglomerate at all, but only a thin "passage bed" at the base of an incomplete overlapping Lowville section to mark the even greater hiatus at Middleville, where it rests on Saratogan (Little Falls) dolomite, and at Little Falls, where the early Canadian Tribes Hill limestone is beneath. And all this on the flanks of old lands that at times have furnished large quantities of detrital material. After such observations it seems quite proper to find new limestone formations beginning with sediment no less pure than that above them.

STRATIGRAPHIC HIATUSES

Frequent absence of clastic material at base of overlapping formations not extraordinary.—That in many good exposures scarcely a trace is to be seen of the imperfectly stratified initial deposits referred to in preceding paragraphs will seem to many a strong argument against the assumption in such cases of emergent conditions. In other words, they may claim that in the absence of subaerially produced clastics, and perhaps of other clear evidence of land decay and erosion, other possible causes of stratigraphic hiatuses should be given preference. Willis[51] ad-

[51] Bailey Willis: Science, N. S., vol. 31, No. 790, Feb. 18, 1910, p. 249.

vances the suggestion that marine current scour is responsible for many of the local breaks in sedimentation, saying that "marine waters may not only deposit sediment, but may also prevent deposition, or even remove a deposit previously made." However, as shown on pages 362 to 375, marine currents can not possibly account for more than a very small percentage of the imperfections in the sedimentary column whose existence is proved beyond any reasonable doubt by faunal and physical evidence. So far as I can see, no other conclusion is possible under the circumstance than that land surfaces frequently existed in Paleozoic time which, on resubmergence, left no depositional evidence of subaerial decay and erosion.

But, after all, is the absence of such evidence to be regarded as extraordinary? I think not; and most certainly I can not concede that the condition is impossible, nor even improbable. Considering the kind of lands that must have prevailed in regions where such obscurely indicated emergences, the Eopaleozoic more particularly, are most common, the sedimentary record in the adjacent continental seas is as complete as it could be made under the circumstances. Let us, then, seek to interpret geologic history according to the facts as we find them and not solely according to criteria suiting conditions prevailing today.

The mere absence of distinctive shore deposits surely does not outweigh all the other evidence on which small low lands and shallow seas is inferred. This negative evidence goes no farther than to suggest that the lands were too low and the seas too shallow to favor the development and accumulation of such material. But there are other lines of reasoning that may be brought to bear on this problem.

That the Paleozoic interior lands were as a rule very low may be accepted as an established fact. Erosional processes consequently affected them only to a very small, not to say negligible, extent. There must have been some surface decay, but unless we assume that the lands were generally clothed with abundant plant growth—a most improbable condition prior to the Devonian—even this can not have been very great. Soil must have formed slowly and, with few or no vascular plants to facilitate its downward extension, it must also have required a long time to attain any considerable depth. Doubtless, too, its particles were very finely divided. Finally, study of Paleozoic unconformities shows that surface inequalities that are evidently due to irregularities in superficial rock decay became common only after the Silurian.

With slow submergence of such a land the advancing sea must have taken nearly the whole of the residual mantle into suspension. Some of it may have been swept into whatever hollows there were, but most of the

finer particles were probably carried seaward and later deposited with the normal sediments of the time. If proper clastic material was available, then it was arranged to form a beach. If not, then whatever littoral fauna was present attached itself to or bored into the bare rocky floor, and was finally buried beneath normal marine sediment in which land detritus constituted but an insignificant part.

Time values of stratigraphic hiatuses. — The chief difficulty about overlaps and unconformities lies in the determination of the time value of the hiatus. None of the physical criteria are competent to give a reliable clue to its durance at any given point. A break corresponding to several geological periods may be no more clearly marked than the relatively brief interruption of sedimentation between two small formations or between diastrophically distinguished members of a single formation. In fact, in equally good exposures it is more difficult to detect the contact between lower Pennsylvanian and Ozarkian sandstones in the vicinity of Bolivar, Missouri, than to find the boundary between the Jefferson City and the Yellville, in Arkansas, or the sharp line between early and later limestones of the Black River group at many places in the Mohawk Valley in New York. It makes little difference whether the compared sequences are lithologically similar or dissimilar; the large hiatuses are, as a rule, no more clearly defined than the small breaks.

Faunal evidence alone gives an immediate clue to the time value of the hiatus. Wanting this, a fair idea of its relative importance may be gained by tracing the break into areas where the sequence is more completely developed. The stratigraphic method is illustrated by figure D on page 450, which shows how various formations are locally intercalated in the hiatus between the Boone and the Ozarkian Jefferson City dolomite in north Arkansas.

Illustrative examples.—Six additional examples may be cited, with barely sufficient discussion of their salient features to illustrate the more commonly observed differences in unconformable stratigraphic boundaries:

The first is the Ordovician Foster Mountain embayment, which is shown in cross-section in figure E, on page 450, and is sufficiently described in the legend accompanying the plate. It illustrates deposits in a submerged valley, the bordering lands of which were comparatively steep and supplied an unusually large amount of loose surface material. The example is important, because it shows that in a rapidly deepening sea, even under such favorable conditions as regards supply, the fine as well as the coarse matter of the regolith is likely to be dropped within short

distances of the strandline. If the bottom had declined more gently the fine material would have been carried farther out by the undertow.

The second example is the contact between typical Lowville limestone and an older, probably late upper Chazy, limestone, seen at Fort Loudon, Pennsylvania. The top surface of the lower bed suggests subaerial corrosion. On resubmergence 0-2 or 3 inches of calcareous clay, presumably mostly surface wash, was swept into the small hollows, while the more prominent parts were largely covered by fixed organisms such as Bryozoa and crinoids. The first foot or so of the succeeding deposits includes a fairly representative littoral fauna, but the matrix is rather pure limestone.

The third is one of many similar examples observed in the Mohawk Valley of New York, where the Lowville limestone is very incompletely represented, and followed directly by either late Black River (Amsterdam limestone) or early Trenton limestone. The upper surface of the Lowville is usually smooth and often pierced by small vertical worm burrows. The contact with the overlying formation is very tight and as a rule shows no trace of land wash material. There was probably very little of this to begin with and what there was must have been quickly carried out. The new precipitation, then, was laid directly on a cleanly washed floor of Lowville limestone.

The fourth example was observed in the quarries at Darlington, Wisconsin. In most respects this case is like the last, and the rocks involved are of similar ages. It differs, however, in that a part of the original surface wash is preserved in a cavern, into which it was probably swept by waves and tidal movements of the water. (See further remarks, pages 364 and 466.)

The fifth is an interesting contact between early Helderbergian limestone and the Onondaga limestone recently observed at Manlius, New York. The contact is clean and sharp and, although the surface of the lower limestone was roughened by subaerial decay and Oriskany sandstone occurs near by, there is no trace of land detritus.

The sixth example is even more surprising. It is the well known contact between a highly inclined and eroded Ordovician sandstone formation and a late Silurian or early Helderbergian limestone at Rondout, New York. The unexpected feature in this case is that whereas the eroded edges of the sandstone layers formed a very uneven, sharply ribbed surface, the succeeding limestone deposit reaches to the bottom of the furrows without intervention of land detritus. Evidently, when this sandstone area was submerged the advancing sea immediately proceeded

to wash the surface clean of all loose material. That it succeeded in doing so in this case must forever silence the argument against the assumption of land conditions without evidence of subaerially produced surface materials. (See figure 17 B, page 450.)

PHYSICAL EVIDENCE OF SEA WITHDRAWAL

It is generally believed by geologists that in past geologic ages marine waters pulsated back and forth over areas now comprised in the continental land masses. The more important of these transgressions were legitimately inferred long ago on good stratigraphic and paleontologic grounds, and they rightly formed the basis on which geological time was subdivided. Progress in our science since its early and middle stages has been largely confined to the accumulation of data and to occasional attempts at refinement in the way of closer discrimination and readjustment of the long established major boundaries. More recently the local components of the several systems were subjected to critical study. On comparison it was found that great diversity of expression and development exists. The fossils were not exactly alike, the lithology was different, and the stratigraphic boundaries indicated in one area seemed not to harmonize with those in another. Evidently something was wrong.

The fault lies in holding too long to the idea of great continental seas and in overestimating their durance. Under this primitive and long treasured conception local absence of deposits of certain ages had to be ascribed to removal by erosion; but as the imperfections in the stratigraphic sequence continued to multiply, while the discovery of adequate amounts of erosion material, especially in the interior areas of flat-lying rocks, lagged far behind, and, more important yet, since detailed investigations of overlapping formations proved over and over again that their upper beds not only spread farthest, but were often preserved despite long exposure to subaerial conditions, some modification of the prevailing conception became imperative. The belief in broad, deep, and long enduring continental seas—seas that began early in the Cambrian and continued spreading wider and wider until well toward the close of the Ordovician—must be abandoned. In its place we should conceive of smaller, very shallow, and frequently shifting bodies of water, of seas that filled a given basin in one age and were withdrawn in the next, that returned again and again in familiar patterns, though perchance from different quarters, in succeeding geological ages. In short, seas that migrated in and out of the structural basins—sometimes extending far across the continents and at other times limited to much smaller areas—

as many times as the number of the diastrophically distinguished "ages" into which the geological time scale is divided.

This revised conception, however revolutionary it may seem at first, is after all merely a logical refinement of the old, an application of the same ineradicable principles to the minor as well as the major divisions of the geological column.

Evidence of sea withdrawal has been discovered in many parts of the stratigraphic sequence where none had previously been suspected. This is not because geologists then were either less diligent in their field work or less keen observers than are those of the present generation, but because they had bound their minds and perceptions by certain beliefs, and because they knew and employed only those criteria that under these conceptions alone seemed competent. They recognized shallowing of the seas and shores by the presence of ripple-marked and sun-cracked beds, by trails of creeping things, by tracks, impressions of rain drops, conglomerates, and other phenomena commonly seen along the present shores of the sea; and they knew that tilted marine deposits, the edges of which had been planed down and subsequently covered with approximately horizontal beds, signified previous elevation and subaerial erosion. Presently unconformities between horizontal beds were recognized, and, at first tentatively, then more confidently, interpreted as general elevation into land and resubmergence without conspicuous folding. And so it has gone on and on, perhaps unconsciously, to the present time, when some geologists at least, postulate land areas at almost all such times and places as are indicated by imperfections in the sequence of marine sedimentation. Conviction in this matter of frequent alternation of emerged and submerged conditions seems, indeed, to have progressed so far that the burden of proof now lies with those who deny the proposition rather than with those who affirm it.

PHYSICAL CRITERIA OF STRATIGRAPHIC UNCONFORMITY

Of the various physical phenomena indicating emergence, stratigraphic unconformities doubtless are the most common and most reliable. But it is only when the contact line is boldly irregular, or when the discordance in bedding is great enough to be easily measured, that the unconformity is immediately distinguishable from the average bedding plane. These strongly marked cases are relatively few as compared to the many that are far from conspicuous and which often require corroborative evidence before their true nature can be established. The characteristics of clearly defined unconformities are so well known that further

description seems unnecessary. We will, therefore, proceed at once to the discussion of the more obscurely manifested instances.

Every sharp faunal or lithologic break suggests a stratigraphic hiatus and, hence, an unconformity and preceding sea withdrawal.[52] If the zone in which the suggested unconformity must, if present, occur can be narrowed down to a few feet by continuity of faunal evidence carried downward from above and upward from below the final detection of the plane of unconformity is usually accomplished quickly and satisfactorily. But when the fossils are scarce, or of kinds that are not very definite in their age relations, then the problem is more difficult. In such cases all sharp lithological changes in the undetermined interval should be investigated for possible clues. Assuming unfavorable distribution of conclusive fossil evidence, those unconformities which occur between two lithologically similar formations are, for obvious reasons, the most difficult to find. Still, many unquestionable unconformities between two limestone formations have been satisfactorily located. It is to be admitted, however, that in most of these cases abundant fossil evidence assisted materially. Instances of directly superposed unconformable shale formations without intervention of a bed of sandstone or conglomerate are more rare. When they occur the determination of the hiatus is almost impossible except by proving gradual intercalation of distinct lithologic units. The Woodford-Caney contact in Oklahoma, which shale formations are locally separated by the Sycamore limestone, is a good example.

When two well marked faunal zones, or two persistent beds easily recognized by lithic peculiarities, are traced from place to place and found to diverge or converge, as the case may be, the fact almost invariably indicates the presence of an unconformity in the intervening measures. The upper formation obviously must be limited below by overlap structure, and the first step in locating the unconformity is to find the line along which the additional beds are intercalated. All of these intercalated beds may be referable to the base of the overlapping superior formation, but when the lower formation has been truncated by erosion one or more may belong beneath the unconformity. Again,

[52] It is to be understood that the lithological aspect of fossils rather than their biological relations are referred to here. Viewed as lithologic features of the rocks, their significance is distinctly stratigraphic and useful in the same way that phosphatic pebbles, glauconite, and other mineral substances that are distinguished by peculiarities in crystallization, color, hardness, and composition are employed in the identification of certain beds. The stratigrapher can and often does use fossils in this limited way without pretense to paleontological training. Of course, with such training fossils assume the additional significance that enables the paleontologist to estimate the relations of isolated stratigraphic occurrences to the generalized standard time scale.

as shown in figure D, page 450, the intercalated beds may themselves bear unconformable relations to both the superposed and the underlying stratigraphic units.

The principal lithologic criteria employed in locating the line of unconformity were mentioned in discussing the peculiarities of initial deposits in relation to overlaps (see page 454). Here we need to emphasize only those bearing more directly on sea withdrawal. The most common of these, and from that standpoint the most important, is the red or rusty color that pertains so frequently, though perhaps but locally, to deposits immediately following an unconformity. While practically all red deposits are either directly or remotely related in their origin to subaerial decomposition processes, and are thus connected with land conditions, it does not by any means follow that all deposits of this color are indicative of stratigraphic unconformities. On the contrary, the larger accumulations of red sediments are not directly associated with such structural phenomena. Often they begin considerable distances above the recognized unconformity which, moreover, may show no red deposits at all, even when a basal conglomerate is present. An instance of this kind was observed in the Wichita Mountains of western Oklahoma, where presumably Permo-Carboniferous "red beds" overlapped on early Ordovician limestone. It is the thin beds of this color, say from an inch or two to not over two feet in thickness, that separate two limestones, or a calcareous shale from an overlying limestone, that are especially significant in this connection. This layer is but rarely well stratified, and usually it is softer than the rocks on either side. In weathering it breaks down quickly, leaving a conspicuous, hollowed-out space. Very commonly, too, it is marked by a line of springs. In some cases it seems probable that the rusty color is not original, but is to be attributed to percolation of ferruginous waters.

This basal layer, whether red or not, is often highly suggestive of reworked soil. Soils preserved *in situ,* with erect trunks of trees still rooted in them, have been described. Such preservation, however, in the case of lands being submerged by a sea, could have occurred only under exceptional circumstances. A single probable occurrence of this kind has been observed in lower Paleozoic rocks; and even in this case it seems to be only the deeper part of the subsoil that remained undisturbed; namely, in the vicinity of Eureka Springs, Arkansas, a layer is sometimes seen at the contact between the Jefferson City dolomite and the Yellville formation that seems to be a part of the residual mantle recemented *in situ.* It contains lenses of chert and silicified masses of *Cryptozoon minnesotense.* Weathering on the old land surface, these

broke into pieces in the usual manner, and occasionally one of the fragments became separated from its fellows just as they appear in sections of the residual cover of cherty beds today.

Fossils wholly or partly freed from a limestone matrix by weathering and which, after lodging in hollows of the surface, were subsequently embedded in the first deposits of a succeeding sea, argue convincingly for land conditions and subaerial decay of the limestone surface. This and similar phenomena have been observed frequently. In all of the four instances to be cited the succeeding formation is a soft shale, three of them black shale, the fourth a green shale. The reason for their selection will be mentioned presently.

In the first, seen near St. Joe, Arkansas, the Chattanooga shale rests on an uneven surface of Polk Bayou (early Richmond) limestone. The weathered out fossils of the latter were preserved as phosphatized casts in a thin, imperfectly stratified clayey layer. This was followed by normal fissile Chattanooga shale.

The second example is shown in Calhoun County, Illinois, east of Batchtown, where the eroded surface of a highly fossiliferous Devonian limestone is succeeded by a greenish shale of Kinderhook age.

The third case was observed in excellent exposures, 4 to 8 miles west of Tahlequah, Oklahoma. The emergence seems to have been of relatively brief duration and the area affected probably not very extensive. It occurred after the deposition of a thin bed of Tennessean limestone (only locally present in northwestern Arkansas and in northeastern Oklahoma), and before the first shale of the Fayetteville group was laid down. These two beds constitute the first and second members of the Fayetteville, as described by Taff in the Tahlequah Folio of the U. S. Geological Atlas. Whatever the duration of the emergence in this case, surface decomposition of the limestone continued long enough to form irregular undulations and corrode its fossil contents.

The fourth example was observed on Pilot Knob, 2 miles east of St. Joe, Arkansas. Here the "coal bearing" shale, the third member or formation of the Morrow group, rests directly on the eroded surface of the Pitkin limestone. On removal of previously undisturbed shale, fossils of various kinds were found imbedded in the limestone, but weathered off flush with its worn surface so as to show in section. Other specimens, proving more resistant, showed in relief. Both conditions are exactly duplicated in present-day weathering of Pitkin limestone.

These examples were selected for two reasons: first, because the overlying shale is easily removed and thus permits examination of fresh surfaces; second, because the shale forms an impervious cover and thus

reduces the possibility of underground solution and corrosion to a minimum. The illustrations are therefore perfectly fair and incontrovertible.

Finally, many of the unconformities that are barely distinguishable even to the trained eye, when traced for varying distances are found to exhibit unmistakable evidence of sea withdrawal. We find, for instance—as in the case of the Lowville overlapping the Joachim, 6 miles west of Ste. Genevieve, Missouri, and the contact seen in the quarry at Darlington, Wisconsin, mentioned on pages 364 and 460—that the nearly even surface of the lower formation descends suddenly into an ancient solution cavern that could have been produced only under subaerial conditions. This may be filled with initial deposits of the succeeding formation or with sediments of an age wholly absent in adjacent parts of the section. Many instances of this sort have been described and a still greater number awaits publication. Though most of them are associated with unconformities in which the stratigraphic hiatus is of great magnitude, others no less well developed are connected with emergences that must have been of relatively insignificant duration.

It seems worth while to mention another of these cases of deposits seen only in old cavities, because it indicates a somewhat different history than is inferred in most of the other examples. The phenomena alluded to occur in the vicinity of Thebes, Illinois. Here several late Ordovician channels were observed in the top of the Kimmswick limestone and beneath the unconformable shaly base of the Thebes formation. The latter is of Richmond or early Silurian age, the former late Black River. In one of the channels exposed in a railroad cut south of the town, residual clay and fragments of fossiliferous chert, both evidently younger than the limestone walls of the channel, were observed. They may represent an otherwise unknown later bed of the Kimmswick or possibly some distinct overlying formation. It is inferred from these facts that solution channeling of the Kimmswick occurred during the rather long emergence that prevailed in this general region till resubmergence set in with the Richmond. Portions of the overlying rock, now represented solely by residual clay and a little chert, dropped into these channels and were thus partially preserved, while the remainder of the sheet was entirely removed by erosion from present areas of outcrop. Peneplanation of the Kimmswick in the Mississippi Valley at this time, as described on pages 308 to 311, is positively demonstrable; and it appears further that the Richmond submergence was delayed at this point till after the Fernvale stage. At any rate, the Fernvale is absent here.

Considering the incontestable and highly significant nature of much

of the evidence cited, also the fact that the criteria are as clearly developed in cases indicating a relatively brief existence of land conditions as in those of much longer duration, it seems to me we are justified in assuming actual sea withdrawal and consequent increasing emergence in practically all localities where imperfections of the marine sedimentary record are indicated by faunal and stratigraphic criteria.

Gradational and lithological Criteria

GENERAL DISCUSSION

The leveling processes of nature are ever at work. The high places of the earth's surface are cut down, the low places filled up. Given lands of high relief under average conditions, the erosional agents work not only faster but also less finely than on lands of low relief. In the former the surface rocks are rapidly broken up and carried to the depressions without much decay, in the latter, slow decomposition *in situ* and slower removal of the regolith or rock mantle prevails; and under conditions of approximate baselevel erosion becomes practically negligible. We have then in the composition, degree of fineness, and amount of the clastic matter in a formation fairly definite clues respecting the altitude, the kinds of rock exposed, and the climate prevailing on the land from which the material was brought. Thus limestones, especially when it can be shown that calcareous deposition occurred at the shores as well as farther out in the seas, suggest low land. Shales also, whether calcareous, clayey, or siliceous, usually indicate gentle gradients and comparatively low lands. Fine-grained red deposits commonly indicate submergence of such relatively low lands after a long period of emergence. When the red sediments are coarser, or when they include beds of salt or gypsum, these facts argue for arid climates, but throw little light on the matter of relief of the contributing lands.

If the material is relatively coarse and was transported by water, we infer, or I might say we know, that the contributing land was high or had locally steep gradients. If this coarse material rests on a limestone formation, we are justified in saying that elevation of near-by land areas occurred between the two kinds of deposits and perhaps continued into the time occupied by the deposition of the clastic formation. This elevation may be but a local affair; but if it can be established through the aid of fossils that elevation is similarly indicated in many places—perhaps all over the world—then we conclude that we are dealing with the local aspect of a phenomenon of extraordinary taxonomic importance. It is not essential that vulcanism or strong folding or decidely angular

unconformities be included in the evidence on which a period of world-wide deformation is postulated, since these criteria may have been confined to marginal areas now submerged or to such as were subsequently baseleveled and later covered by more recent deposits. Such criteria may indeed be found in certain areas now accessible to investigators, but being absent elsewhere they are commonly assumed to be manifestations of merely local movement and correspondingly unimportant taxonomically.

PRE-PALEOZOIC PERIODS OF DIASTROPHIC ACTIVITY INDICATED BY GRADATIONAL CRITERIA

Paleozoic periods of diastrophic activity thought to be of the highest rank are indicated by data which, though incomplete, may be interpreted satisfactorily. The late pre-Cambrian period of activity is generally suggested by the unconformable relations of the Cambrian to the underlying crystallines on which it usually rests. But as a rule we know little concerning the time value of the hiatus at the base of the Cambrian. The Proterozoic covers a very long time, and we are seldom able to decide positively just which part of it, if any, is represented by the rocks beneath the Cambrian. In most cases these rocks are much older than the Belt series which, in the Great Basin, underlies the lower Cambrian with only moderately angular unconformity. Lithologically, the Belt series is not greatly different from the lower Cambrian, so that in areas where the two are in contact a grand period of diastrophism and attendant erosion is not clearly suggested. Obviously then, while the postulated pre-Cambrian period of great activity is undeniable, the determination of the actual time relations of the movements is based on rather indefinite data. Nevertheless, I am convinced that the lower Cambrian was laid down during the closing stages of a grand period of diastrophic activity and surface gradation. This conviction rests principally on the fact that gentle folding of the Belt series, which lies in the negative Cordilleran basin, occurred before the Cambrian, and on the probability that the major folding and erosion of the time took place on the more positive areas of the continent. At the same time it seems highly probable that the folding and consequent erosion of the Proterozoic rocks, other than the Belt series, belongs in part to much earlier periods.

LATE ORDOVICIAN-EARLY SILURIAN PERIOD OF ACTIVITY

It is on the same kind of evidence—the invariably clastic character of the deposits and their great thickness in areas commonly given over to limestone deposition during the Paleozoic—on which the early Cambrian period of diastrophism is based, that a similar period of activity is

assumed at the close of the Ordovician and another at the close of the Tennessean. There has been no greater or rather more general break in the sedimentary record of the continents and in the evolution of fossil marine organisms than occurred in the time between the closing stages of the Ordovician and middle stages of the Silurian. Through vigorous diastrophism probably was largely confined to areas close to the margin of the continents, where its evidence has since been obliterated or buried (see pages 435 to 440), there is yet positive testimony of folding and erosion in eastern New York and New England that must have occurred about this time. In the Mississippi Valley and thence westward to the Great Basin slight elevation, beginning locally with the close of the Black River, but accomplishing complete emergence only at the close of the Trenton, seems to have prevailed to the beginning of the Richmondian. During this emergent phase baseleveling, as described on page 308, was in progress in the Mississipi Valley. In the Appalachian region shale deposition began in many parts of the valley during the late Chazyan, and before the close of the period heavy sandstone formations (Oswego and Juniata), thought to be land deposits, were laid down in the northwestern portion of the valley in Pennsylvania and New York. Sandstone deposition, with possible change in climate, continued here into the Silurian, which began in this region with the Tuscarora quartzite ("white Medina"). Thick deposits of shale and sandstone, the latter more local in distribution than the former, were deposited about this time also in the Ouachita geosyncline in western Arkansas and eastern Oklahoma.

The fact of prime significance brought out by study of the deposits in the principal areas of Eopaleozoic rocks is that the predominatingly clastic lower Cambrian deposits were followed by great series of limestone strata containing, except locally, but a small percentage of fragmental matter. In the Appalachian Valley these limestones attained an aggregate thickness of fully 15,000 feet before the late Ordovician and early Silurian deposition of highly clastic material set in. The extraordinary importance of this fact is apparent when we consider that in the intervening relatively quiescent stages the valley was repeatedly subjected to warping and consequent sea shifting, while on at least three occasions complete sea withdrawal occurred. Obviously, the movements which occasioned these intervening oscillations were inferior in vigor and extent of areas prominently affected than was the early Cambrian deformation which preceded and the early Silurian which succeeded them. That the latter effected unusual elevation even in the interior areas of

frequent uplift is shown by the shaly and locally sandy nature of the Richmondian deposits in Oklahoma, Missouri, Iowa, and Wisconsin. These Richmondian sediments are in striking contrast to the underlying pure and dolomitic Ordovician limestones. Judging from their characters they suggest finely divided surface wash from old deeply decayed lands sufficiently elevated to permit of gentle denudation.

The probably wind-blown pure silica sands of the Saint Peter and of the less widely distributed sandstones in the Ozarkian system in the Mississippi Valley indicate large land areas to the north, northeast, and northwest at such times; but these emergences were less in extent and diversity of relief and, excepting the Saint Peter, also of shorter duration than the late Ordovician emergence. Besides, these earlier emergences are scarcely suggested by change to clastic deposition in the Appalachian Valley, indicating that western Appalachia was never high during the late Cambrian, the Ozarkian, Canadian, and most of the Ordovician ages. As the deposits in the Appalachian Valley give the fullest known record of Paleozoic events in a single province, it is regarded as the best standard for determining the extent and time values of the submergences and emergences on which the proposed revision of the Paleozoic systems is based. Where defective, the Appalachian record is pieced out from other regions, as the Cambrian, which is better developed in the Cordilleran basin, the earliest Ordovician, which is more fully represented in the Arbuckle uplift in Oklahoma, and the middle Silurian, which is much better recorded in New York, Tennessee, Indiana, and Wisconsin. Yet other parts of the stratigraphic column are more completely represented elsewhere than in the Appalachian Valley, as the lower Devonian in Gaspé, the middle and upper Devonian, the Mississippian, and the Pennsylvanian in the Cordilleran basin, but these sections are at present less satisfactory than the Appalachian, because the movements and corresponding breaks in the sedimentation are either less clearly indicated or the exposures have not been studied with sufficient regard to stratigraphic details.

NEOPALEOZOIC DIASTROPHIC PERIODS

The depositional history of the next era, though similar to that of the Eopaleozoic, is complicated by the greater proportion of clastic matter contained in the middle systems (Devonian and Waverlyan). This may be explained, according to the theory of inland migration of the belt of folding (see pages 435 to 442), by assuming increasing elevation of lands contributing to the Appalachian Valley and to areas elsewhere that are similarly located with respect to the margins of the continents.

Beginning with the Silurian, we see in the finely divided clastic matter of the Richmondian deposits in the Mississippi Valley the rather scant sedimentary result of erosion on the slightly elevated median lands. The Niagaran deposits which follow them consist almost entirely of limestone. In the Appalachian region, however, the lands were higher and contributed clastic material to the valley troughs longer, so that here we find sandstone deposition continuing locally to the close of the Clinton.

The succeeding Silurian and early Devonian formations in the Appalachian Valley consist mainly of limestone, but, beginning with the Oriskany and ending with the Waverlyan, the deposits in the middle and northern parts of the valley consist almost entirely of shales and sandstones. In the southern part, however, especially in Alabama, the upper part of this interval is decidedly calcareous, sandstone and shale being confined to the lower and middle portions. In the median and far western parts of the continent the Devonian is represented almost entirely by limestones. This is true also for the Waverlyan in and to the west of the Mississippi Valley, but east of Illinois this system comprises little else than shale and sandstone. From these facts it has been inferred that considerable elevation of the northern and middle parts of the Appalachian region occurred during the Devonian. Judging from the great volume of deposits in Pennsylvania and southern New York, the land contributing to this area doubtless attained greater altitudes than did its southern extension. Indeed, there is reason to believe that Appalachia was cut in two by submergence in the region of Chesapeake Bay. Further, since the larger part of these deposits is of late Devonian age, we naturally conclude that the elevation of the land reached its maximum during this time. That this maximum was in anywise comparable to that of the Sierra Nevada of California, as suggested by Willis,[53] seems improbable. On the contrary, it is thought that this land never attained such altitudes and that the great mass of sediment removed from it is owing rather to repeated elevation during the Devonian and Waverlyan than to a single great upward movement.

The Devonian deformative movements, as indicated by the character and volume of clastic deposits of this age, were almost world-wide in extent. Comparing these deposits in the several continents, the geological history of this period seems to have been even less pacific in Europe than in America and elsewhere. In western Europe especially volcanic rock is frequently interbedded with the stratified deposits; and in the

[53] Bailey Willis: Paleozoic Appalachia. Maryland Geological Survey, vol. 4, 1902, p. 62.

British Isles are found areas of "Old Red sandstone"—in part at least land and lake deposits—of great thickness, that are commonly believed to represent several distinct basins. Erosional unconformities occur within these deposits, showing that considerable, though perhaps local, changes of level were taking place.

While warping and local emergences occurred rather frequently during the Devonian in America as in Europe, it is yet a fact that, on the whole, this was a period of progressive overlap. The Helderbergian or lower Devonian deposits everywhere are overlapped by the middle Devonian and this, in many places at least, by the late Devonian. In eastern America the lower Devonian contains much less clastic matter than in west central Europe, but that would seem to be due to the fact that whereas in America the Helderbergian invaded late Silurian limestone areas, from which but little clastic sediment could be derived, in Europe the early Devonian sea advanced over a much older and probably soil-laden land. The middle and upper Devonian deposits are essentially similar in the two continents, the former consisting chiefly of limestone, the latter of sandstone and shale in western Europe and eastern America and mostly of limestone in the more inland areas. In both America and Europe the lower Devonian was deposited in old downwarps which from time to time in the preceding Paleozoic ages had been accentuated. These downwarps suffered little erosion, the contact between the base of the lower Devonian and the underlying rocks being, therefore, as a rule not conspicuously unconformable. But the upwarped boundaries of the old troughs or basins: these were eroded; hence where the middle Devonian overlaps on them marked unconformities prevail.

It is fairly well established that no very important deformation occurred at the close of the Silurian and the beginning of the Helderbergian Devonian. The character and distribution of the sediments of the latter indicate oscillating though on the whole gradual subsidence of intramarginal troughs, like the Appalachian Valley, and corresponding slowly advancing submergence of such troughs. Prior to this time, however, occurred the important late Ordovician-Silurian emergence, which, strange to say, was revived and attained considerable dimensions in the Appalachian Valley during the middle Silurian (late Niagaran). This statement is based on the fact that, although the Clinton (including the Rochester shale) is well represented in this valley, no trace of later Niagaran deposits has been found there. It is to be noticed, however, that the middle Silurian emergence of the Appalachian Valley referred to probably was not accompanied by disproportionate elevation of the adjacent areas which had contributed the clastic material of the preceding

Clinton, Tuscarora, Medina, Juniata, and Oswego formations. These lands I regard as having been nearly baseleveled at the close of the Clinton, and that following the Clinton they merely shared in a general elevation that embraced the whole Appalachian region. This conclusion is based (1) on the fact that the last deposits of this group or formation locally consist chiefly of limestone, and (2) on the similar fact that the Cayugan and Helderbergian deposits which succeed them in the middle and northern parts of the valley consist almost entirely of calcareous mud rocks and pure limestones.

Warping strong enough to effect the resubmergence of a large part of the Appalachian Valley (Tennessee to New York) and to produce lagoons and more or less effectively inclosed basins farther inland was deferred to the Cayugan, during which time, apparently, the latter condition prevailed in a notable degree also in the British Isles. But there is no sedimentary evidence of folding at this time in any region near enough, or so situated that it could contribute distinctly clastic material to deposits now accessible. The hiatus that separates the "transition beds" beneath the Coeymans from the Manlius, at Schoharie, New York, and the older Helderbergian (Keyser) rocks from the Cayugan in the middle and northern Appalachian Valley, together with the total absence of lower Devonian beds in all of the median regions of the North American continent north of Saint Louis, suggests sufficient actual and relative elevation to insure total withdrawal of continental seas at the close of the Silurian. Between the operation of forces resulting in suboceanic spreading on the one side and continental creep on the other, the Appalachian Valley geosyncline accommodated itself to the strain by subsidence to stages permitting earlier return of marine waters here than elsewhere. The Helderbergian limestones laid down at this time show that no folding of consequence occurred in adjacent areas. Such folding is indicated a little later by the locally highly clastic deposits of the Oriskany. Some elevation and warping of Ozarkia also is indicated at this time by considerable deposits of quartz sand containing Oriskany fossils, which occur locally in southern Illinois and possibly extend beneath younger formations into north-central Tennessee. Subsequently, Ozarkia contributed similar amounts of quartz sand to the late Devonian limestones on its north flank and again when the Chattanooga shale, with its introductory Sylamore sandstone, overlapped its southern side. Appalachia, Taconia, and the Adirondack uplift, however, continued to supply finer or coarser clastics to the close of the Waverlyan. Evidently the belt of gentle folding had moved farther inland in the Neopaleozoic than it was in the Eopaleozoic. (See figure 16, page 440.)

RELATIVE IMPORTANCE OF DEVONIAN DEFORMATIVE MOVEMENTS

Was this Devonian period of diastrophic activity comparable in taxonomic importance to the preceding late pre-Cambrian and late Ordovician-early Silurian periods, and succeeding Chester-Pottsville and the late Mesozoic-early Cenozoic movements? I think not. If there is any truth in the suggested theory of inland migration of the continental belts of active folding, then the importance of the Devonian movements, as indicated by the predominance of clastic deposits of this age in the Appalachian Valley, is more apparent than real. It is doubtless a fact that the balance of vertical movements, at any rate for the North American continent, has favored elevation rather than subsidence. The average height of the continents and even more the inequalities of their surfaces have been greater since the beginning of the Pleistocene than at any previous Mesozoic or Paleozoic time. This is shown by the notable decrease in limestone deposition in the interior areas since the Ordovician. Subsequent to the Silurian continuous deposition of limestone to thicknesses of 500 feet or more are confined to the southern Appalachian and southern Cordilleran basins and besides these to areas south of the 35th parallel. However, most of this change from limestone to clastic sedimentation, in so far as it affected the interior areas, came after the Tennessean. The average relief of the median areas, as shown by the composition, distribution, and volume of deposits, remained essentially the same during the Devonian, Waverlyan and Tennessean periods as it had been in the preceding Ordovician, Canadian, and Ozarkian. During all these periods the interior lands were low and, as a rule, almost featureless; and the clastic matter derived from them, therefore, was commonly not only very scant but also very fine. But, although the general relief of these lands was not greatly augmented, the growing frequency of change in character of deposits shows corresponding increase in diversity of surface features.

There are occasional exceptions to the rule of fine and scant clastics derived from the median lands during these relatively quiescent periods. Thus they provide reasonably coarse quartz sands when the Saint Peter, Sylvania, and Berea sandstones were spread southward from the Canadian areas of pre-Cambrian crystalline rocks. But of the instances mentioned the first two suggest eolian means of distribution—a mode of transportation that is effective when streams, on account of the slight grade, must fail. Even in the case of the thin sandstone beds on the flanks of Ozarkia (Oriskany, late Devonian and Sylamore), which were carried from exposed areas of Saint Peter and older sandstones on this land,

eolian agencies may have been more important in the transportation of their constituent materials than water.

The late Devonian and Waverlyan clastics spread far inland in southeastern America from their Appalachian sources. There are no limestones worth mentioning in the upper Devonian of New York, Pennsylvania, and Ohio, nor in the Waverlyan, east of Illinois and north of east Tennessee. The lower half to two-thirds of the succeeding Tennessean, however, is made up, in the Appalachian Valley as in the Mississippi Valley, of nearly pure limestone. Evidently a long time intervened, during which the land which previously supplied the Devonian and Waverlyan clastics in this middle Appalachian region was reduced to a condition of approximate baselevel. The only region in this country in which rocks apparently of early to middle Tennessean are are not limestone, or at least highly calcareous shale, is in northern Arkansas (Moorefield shale and possibly Batesville sandstone). Considerable bodies of limestone, in part at least of Tennessean age, occur in the far west.

THE LATE TENNESSEAN-EARLY PENNSYLVANIAN PERIOD OF DIASTROPHIC ACTIVITY

This quiescent stage was followed by the introductory phases of the third grand diastrophic period or revolution. These began early in the Chester series of the Tennessean—that is, with the Cypress sandstone in the Mississippi Valley and the Batesville sandstone, the lower part of which is probably somewhat older, in northern Arkansas.

Both these sandstones derived their material wholly (the Cypress) or in part (the Batesville) from the Ozark uplift, which had been just sufficiently emerged in the preceding Meramec epoch, to neither receive deposit nor to contribute more than insignificant amounts of clastic material to the St. Louis and Spergen limestones which lie on its eastern flank. However, during the deposition of these limestones, the surface of the low land, which was largely covered by the cherty limestones of the Osage, was being deeply decomposed and thus being prepared to supply the fine sands of the Cypress and part of the Batesville[54] when the Chester elevation began. While the Devonian and early Kinderhook sands derived from Ozarkia are readily identifiable as reworked St. Peter sandstone, those of Chester age in no wise suggest the characteristic rounded quartz grains of that formation. On the contrary, especially those on the east side, look like the finely assorted wash of a deeply de-

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[54] A large part of the material of the Batesville, like that of the preceding Moorefield shale of the same region, was probably taken from older sandstone and shale formations to the south and southwest (Ouachita region), which at this time were slightly folded and emerged and subjected to erosion.

cayed silicious limestone soil. Another peculiarity of the Chester sandstones in southeastern Missouri, southern Illinois and western Kentucky, tending to show the same source, is the rarity or total absence of mica flakes. It proves at the same time that these sandstones were neither derived from distant areas of crystalline rocks, nor from older misaceous sandstones that were subjected to erosion at this time. This mineral, however, is a common constitutent of the Chester sandstones in northern Arkansas and in the Appalachian Valley, while it is rarely absent in any of the Pennsylvania sandstones of southeastern America.

Though considerable beds of limestone occur in the Chester, particularly in the lower half, the greater part of the total thickness of the deposits of this epoch in southeastern America consists of shale and sandstone. Ozarkia was emerged throughout the Chester, but not as a fixed land, oscillatory movements and occasional accentuation of its upwarps being clearly suggested by adjacent deposits. Thus upward movement is indicated at the close of the Tribune limestone by thin local chert conglomerates at the base of the shaly and sandy Birdsville formation in southeastern Missouri. The repeated alternation of sandstone, shale and limestone deposition in northern Arkansas, beginning with the Batesville sandstone and ending with the Pitkin limestone, the local distribution of some of the beds, and the petrologic character of the clastics indicate yet other differential movements in Ozarkia and probably in Llano as well. A later post-Birdsville Chester movement is recorded in the Appalachian valley by the conglomeratic Princeton sandstone. This preceded the last of the deposition of rather finely divided clastics (Bluestone formation of southeastern West Virginia and the Parkwood formation in Alabama) with which the known sedimentary record of the Tennessean closed in southeastern America. An hiatus of great but undetermined time value succeeded.

Great shrinkage movements, resulting in extraordinary elevation of marginal lands, especially of southern Appalachia and Llano, probably began in this interval. This is indicated by the enormous thickness of lower Pottsville shales and sandstones found in northeastern Alabama and in the Ouachita geosyncline in Arkansas and eastern Oklahoma. In the Ouachita region these attained a maximum thickness of something like 15,000 feet before the northward and westward overlap of the Caney shale, which is in part represented by the upper black shale of the Morrow group in northern Arkansas, set in. In the meantime considerable progress had been made toward baseleving of interior areas of uplift, like Ozarkia, so that this shale transgression rapidly covered a wide area in the Mississippi Valley. The importance of this period of diastrophism

is further manifested in the fact that this enormous thickness of early Pottsville deposits occurs mostly in greatly deepened troughs that for long preceding ages received no known deposits. This is true particularly of the Ouachita troughs, in which the early Pennsylvanian Stanley shale and Jackfork sandstone follow the Arkansas novaculite, a formation that can not be younger than the Waverlyan and is most probably much older—that is, Oriskanian.

DEDUCTIONS BASED ON GRADATIONAL CRITERIA

From the above incomplete array of facts and more or less probable inferences, the following deductions may be drawn: (1) that the interior regions of the continent from the Cambrian to the close of the Tennessean never embraced areas high enough to favor rapid denudation; (2) that the clastic material in most of the Paleozoic deposits in southeastern North America was chiefly derived from the relatively high lands bordering the north Atlantic and the Gulf of Mexico; (3) that the Devonian diastrophic movements were not really more important than those in the Ozarkian, Canadian, Waverlyan, and Tennessean periods; (4) that the Devonian movements were inferior in consequence to the late pre-Cambrian, late Ordovician-early Silurian, late Tennessean-early Pennsylvanian, and late Mesozoic-early Cenozoic deformations; (5) that the predominance of clastics in the Appalachian Devonian deposits, on which the prevailing belief concerning the great importance of the movements of this age is chiefly based, is due to the inland migration of belts of folding (which at this time had reached areas contributing freely to the Appalachian Valley troughs) and not to extraordinary activity, and (6) that the late Tennessean-early Pennsylvanian period of deformation is the third of four coordinate, grand periods of diastrophic activity. For the sake of completeness, it may be said that the fourth of these grand periods began in the late Cretaceous, the second in the late Ordovician, and the first in the pre-Cambrian.

LATERAL CHANGE IN CHARACTER OF SYNCHRONOUS DEPOSITS WITHIN THE SAME BASIN

Change not the rule.—It is commonly believed that all synchronous deposits change more or less decidedly when followed from place to place. This conception being founded on familiar conditions prevailing along the seashores of today, it naturally commands credence and respect. Perhaps no other partial truth has done more to impede progress in stratigraphic correlation and paleogeography than this plausible fallacy.

It is not that the rocks do not change in lithic character along the strike, for they do, and sometimes very greatly. The fault lies in the general, more particularly in the indiscriminate, application of the principle. That deposits within and near the littoral zone must be appreciably different in quantity or quality or in both respects from sediments farther out is too obvious to require demonstration. But that the change is necessarily considerable or even approximately equal in different but corresponding parts of a basin is not true. The change in character and volume of the deposits depends on so many variant factors that it is impossible to frame rules that will be generally applicable and of practical value to the student. Any difference in the altitude, composition, and drainage of adjacent lands and in the climatic conditions prevailing thereon must have exerted some either local or general effect on the character of the marine deposits of the time. (See pages 454 and 467 for further remarks.)

Shoreward change in lithic character of formations has been assumed, generally without argument, or as a self-evident principle, by nearly all authors who have sought to account for, more particularly the observed east-west variations in Appalachian Valley deposits, which they regarded as synchronous. Nevertheless it seems to be a fact that unquestionable occurrences of this kind are really exceptional and certainly not very common. As a rule the presumed lithically changing stratigraphic zones have proved to comprise deposits that were laid down not only at different times but in distinct troughs. For instance, the Knox dolomite in east Tennessee was thought to lose its chert in passing from the west to the east side of the valley. In fact, however, the supposed eastern representative is a later deposit that in turn fails to extend westward across the valley. Similarly the great Chickamauga limestone series of the western side of the valley was thought to change so that at the eastern edge the limestone gave way almost entirely to shale and sandstone. We know now that this is untrue, and that instead of synchronous, laterally changing deposits, the Ordovician rocks of the valley were laid down at varying times in several distinct, though now more or less overthrust, troughs, to each of which certain stratigraphic units, differing lithologically, faunally, and chronologically from the rest, are confined.

As is to be expected, decided lateral change in lithic character of stratigraphic zones is even more exceptional in the interior basins of North America than in the Appalachian troughs. In these also the supposed local variations are usually found to pertain to beds of different and not the same ages, or if not that then to deposits in distinct geological prov-

inces. Thus the Galena dolomite of the upper Mississippi Valley is not of the same age as the pure crystalline Kimmswick limestone found to the south of St. Louis. The Galena is younger. The Silurian dolomites of Wisconsin and Iowa and the purer limestone of the same period in Kentucky and western Tennessee also are most probably not strictly contemporaneous deposits. At least they belong to distinct provinces, within which each series of formations maintains its lithic characteristics without any sign of intergradation in the median areas.

Some lateral change in lithology of possibly contemporaneous zones is suggested by comparison of the Waverlyan deposits in Ohio and eastern Kentucky, with the Fort Payne and Tullahoma formations in Alabama and Tennessee and the Boone and Osage group of limestones in Arkansas, Missouri, and Iowa. Also in comparing the Chesterian deposits in north Arkansas with those in western Kentucky and Illinois. But even in these two cases the exact contemporaneity of the local developments is only in part true or probable, for at least some of the zones of the series or groups in the several contrasted areas did not stretch unbrokenly from Ohio to western Arkansas and Iowa in the first case and around the southeastern flank of Ozarkia in the second. As for the other zones the several basins were sufficiently distinct in features influencing sedimentation to develop corresponding local peculiarities. (See further statements, pages 318, 425, 452, 582, 586 593.)

The case of the St. Peter sandstone.—But there seems to be at least one well marked case of landward change in character of deposit in the Mississippi Valley, namely, the series of deposits of which the St. Peter sandstone is the most important member. As shown in the accompanying sketch, this series begins in the southern embayments of Ozarkia with a thin basal sandstone or fine conglomerate resting unconformably on the Yellville. This is followed without apparent break by from 1 to approximately 100 feet of fine grained, slightly magnesian bluish dove limestone, to which the name Everton is applied. Locally the Everton is thickly charged with floating rounded quartz grains; at other places it is almost entirely free of sand. Usually its top grades rather rapidly into typical St. Peter sandstone, and this in turn passes by gradual transition into the overlying Joachim dolomite.

Tracing the series northward in the Mississippi Valley it is found that the Everton drops out before reaching the border of Missouri. Of the succeeding members the St. Peter sandstone extends far into Minnesota and Wisconsin, but the Joachim, which is still well developed at the

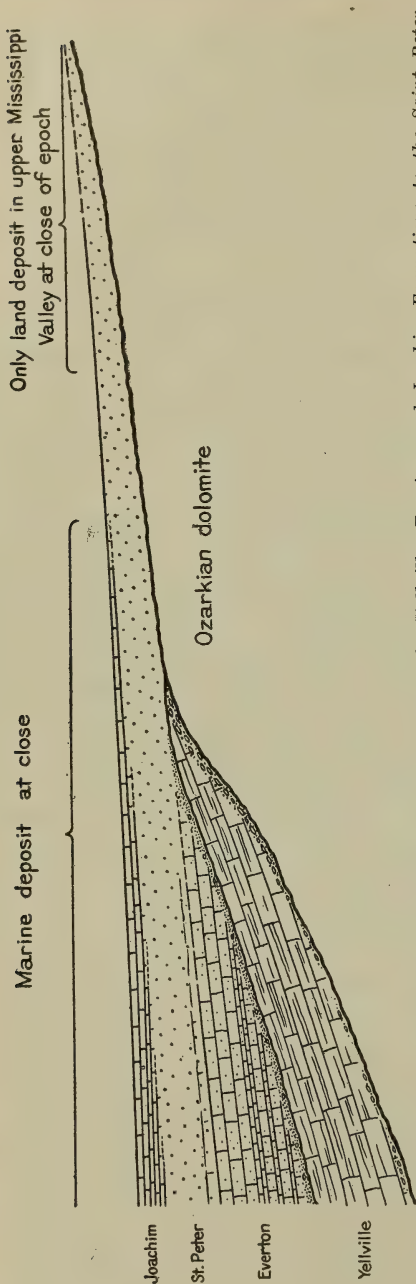

FIGURE 18.—*Diagram illustrating the stratigraphic Relations of the Yellville, Everton, and Joachim Formations to the Saint Peter Sandstone and the northward Overlap of the Last*

The Joachim suggests marine deposits in the wake of the advancing Saint Peter beach

mouth of Illinois River,[55] probably pinches out or becomes unrecognizable in the vicinity of Hannibal, Missouri. The facts in hand are explained as follows:

1. The whole series represents uninterrupted deposition in and adjacent to an advancing shallow sea.

2. The Everton, with its basal layer of sand, represents deposition in embayments while the sea was still confined to areas south of Missouri.

3. The St. Peter sandstone is a well developed beach formed of wind-transported quartz grains from the north.

4. In the early part of this stage the beach seems to have gained on and possibly overcome the advance of the sea in northern Arkansas, but subsequently it was itself progressively drowned and its development pushed northward to some line beyond the present limits of the St. Peter.

5. Finally, the Joachim represents off-shore deposition during the latter half of the time consumed in the tangential deposition of the St. Peter beach sands.

[55] Apparently this is the formation to which the name Folly limestone was applied by C. R. Keyes (Proc. Iowa Acad. Sci., vol. v, 1898, p. 61).

Paleontologic Criteria

GENERAL DISCUSSION

The taxonomic value of fossils is universally recognized. Without them the determination of the sequence of geological events would be incomplete, while the correlation of such events in widely separated regions would be practically impossible. The sequence of the fossils was, of course, originally determined by their relative positions in undisturbed strata, and exact advance in stratigraphic paleontology is still largely dependent on such basic information. But with the great fund of positive paleontological knowledge now available, and from which a more or less progressive scheme of evolution of plants and animals has been worked out, the expert paleontologist of today ventures an opinion concerning the age of previously unknown fossil genera and species. This opinion is based on principles of evolution and as a rule proves reasonably accurate. To a considerable extent therefore the paleontologist has progressed beyond proved stratigraphic sequence.

There are many sorts of fossils, and the taxonomic aspects of the different kinds varies considerably. Remains of marine organisms prove submergence of the area in which the strata containing them are found. When well preserved remains of land animals or land plants are associated in the same layers with the marine fossils then we know that land areas were not far away. Further, when the bed or formation contains only land or fresh water organisms we may fairly assume that this deposit was laid down in an area above sealevel. Finally, when such land deposits are found to alternate with marine sediments in a section then we may infer that the sea migrated to and fro over the land, such parts of the continents being at times submerged and at other times emerged. Obviously, in a classification based primarily on diastrophic movements, causing emergences and subemergences of continental areas, such alternate occurrences of marine and land organisms are of vital importance.

Naturally land animals and plants flourished chiefly in the emergent stages, and more especially in the late, the intermediate, and the early ages of geologic periods when the emergent phases were dominant. Unfortunately, land organisms are but rarely found in deposits older than Devonian, but beginning with this period land plants, and later nonmarine animals, became very prominent. In the Paleozoics, therefore, land organisms constitute criteria of taxonomically important earth movements only in the Devonian and subsequent periods. Certain crustacea, like the Eurypteridæ, which are found in pre-Devonian as well as later

deposits, suggest brackish, lagoon, and possibly lacustrine habitats. These may therefore be considered in connection with non-marine fossils and as similarly indicating accomplished or impending sea withdrawal; but the evidence of the Eopaleozoic species on this point is far from decisive.

FOSSIL FAUNAS AND FLORAS

The terms fauna and flora, as generally accepted, are used in two broad senses, a stratigraphic and a biologic. Several distinguishable meanings are included in the second. The fossil species found in any division of the stratigraphic column constitute the known fauna or flora of that stage. These associations may be referred to by the names of the stratigraphic divisions in which they are found, or they are named from some characteristic genus or species. We have then a Cambrian, an Ordovician, a Devonian, and other faunas of similar rank; or, referring to faunas of lesser rank, the Niagaran fauna, the Clinton fauna, and the Rochester shale fauna. Then we may speak of the Glossopteris or Gangamopteris flora, the Fusipira fauna, and the Manticoceras intumescens fauna. Associations of animals of still lower rank are often distinguished as faunules. Only those of the first rank, as the Ordovician fauna, are truly world-wide in distribution, and for these only the term has the single stratigraphic significance. In those of the second to the lowest order a geographical or provincial significance of the term becomes more and more prominent. Examples of its use in the systematic biological sense would be a graptolite fauna or a crinoid fauna, while such expressions as the Spergen fauna, the Hamilton fauna, or the Tropidoleptus fauna, when applied to other appearances of such faunas than the first described, suggest the biologic sense as much as the stratigraphic. Finally, we speak of littoral, pelagic, and abyssmal faunas, or of marine, brackish, lacustrine and land faunas, or of mountain, swamp, etcetera, floras.

Theoretically, and as a rule, the distribution of a fauna is in proportion to the time value of the stratigraphic unit to which it is credited. But there are many notable exceptions of relatively wide-ranging faunas in thin formational units, and these are of exceptional importance in stratigraphic taxonomy. Such faunas occur at times of great sea transgression and resulting confluence of continental basins, which at other times were occupied by distinct faunas. Some of the Black River and the Richmondian faunas, as described in Part I of this work, and the New Scotland Helderbergian fauna are especially noteworthy examples because their areal distribution transgresses boundaries of commonly distinct provinces. Certain pelagic or planktonic faunas, notably the graptolite

faunas of the Silurian and earlier systems, are of great value in intercontinental correlations. Unfortunately, however, the occurrences of graptolites are largely confined to narrow channels near the margins of the continents and are therefore only occasionally available in determining ages of deposits in more inland basins.

CENTERS OF ORIGIN AND DISPERSAL OF FOSSIL MARINE FAUNAS

Although in the past geologic ages each of the present deep oceanic basins probably was in a greater or smaller degree a center of development and dispersal, comparative studies of Paleozoic faunas in the northern hemisphere suggest grouping these into three major faunal realms, namely, (1) an Atlantic, (2) an Arctic, and (3) a Pacific. When occasion offered these seas and their contained faunas invaded the intervening epicontinental depressions to varying extents and in such manner that many of these basins have been alternately occupied by Atlantic and Arctic or by Arctic and Pacific faunas. In rare instances, as in Oklahoma, faunas apparently derived from all three realms are superposed.

Possibly the continental basins themselves sometimes became centers of origin and dispersal. Indeed, in these basins local "expansional evolution,"[56] a subject that will be discussed in some detail presently, may seem occasionally to mask the invading faunal element that is chiefly to be depended on in distant correlations. Obviously, since the indigenous forms, if such they be, consist mostly of minor departures from strong specific stocks, they are often of exceptional value in exact correlation within provincial or more restricted geographic limits.

Paleozoic Atlantic faunal realm and its subdivisions—The three subfaunas.—The Paleozoic Atlantic fauna seems to comprise three subfaunas: (1) the north middle Atlantic, ranging approximately between the latitude of Newfoundland on the north and Florida and the Antilles, which were occasionally united, on the south; (2) the Gulf of Mexico and the Caribbean Sea, which basins are thought to have been sometimes divided by land connection between Yucatan and the Antilles, and (3) the Mediterranean. As a rule these faunas are readily distinguishable but at certain times, referring more particularly to the American side, the bars appear to have been let down between them. Considerable community between the northern basin and the Gulf of Mexico is indicated toward the close of the Ordovician by faunas found in the Carodoc of Wales and the Cincinnatian in southeastern America. Even stronger commingling occurred during the early Devonian, while from the Waverlyan on to the present

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[56] T. C. Chamberlin: Journal Geology, vol. 6, pp. 457-459 and pp. 600-608.

time the differences between the respective faunas of these three subrealms evidently have been on the whole less than in early Paleozoic times.

The comparative uniformity in bottom faunas then established in the Atlantic doubtless is attributable chiefly to the length of time in which adventitious physical circumstances may have assisted geminate, orthogenetic, parallel, and convergent evolution of long separated faunas in promoting such uniformity. At the same time the process probably was augumented by occasional land or shallow water connections between the

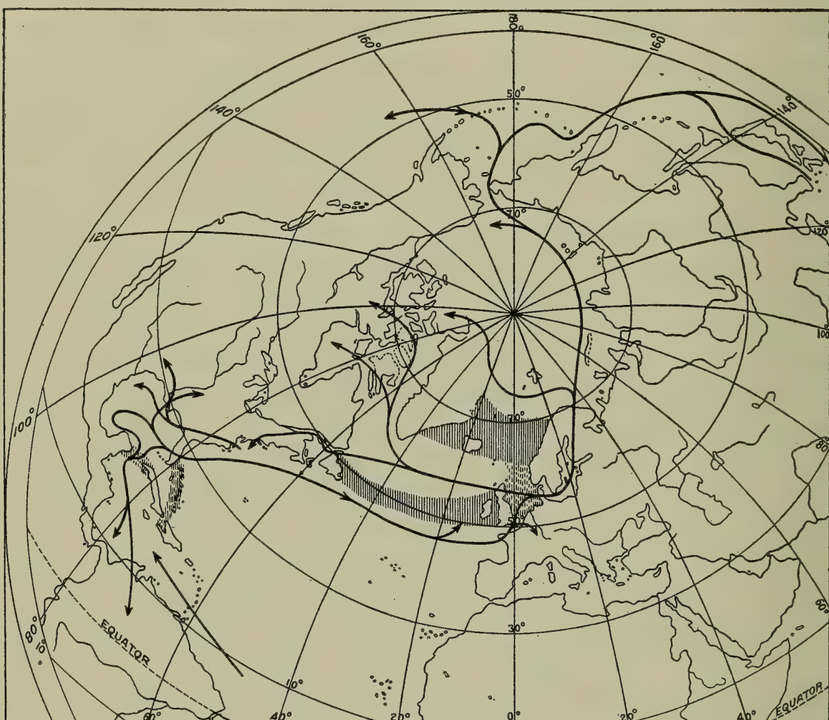

FIGURE 19.—*Map of Portion of Land Hemisphere*

Showing Paleozoic land connections and paths of marine faunal migrations. The vertically lined areas indicate occasional land connections between parts of North America and Europe in the north and with the Antilles in the south.

American continents on the west and Africa and Europe on the east side. It is not readily conceivable how the often close agreements between Paleozoic faunas in western Europe and eastern America could have been brought about except by such means. Conditions favoring littoral migration between England and the Gulf of Saint Lawrence are indicated in the middle Cambrian, the early Canadian, and rather commonly during the

Ordovician and Silurian; also in later Paleozoic ages. The assumed land connection which made these migrations possible served to separate the middle Atlantic fauna from the Arctic fauna in the North Atlantic basin.

The migrations of the pelagic graptolite faunas of the Canadian (Tetragraptus) and Ordovician (Nemagraptus) on the contrary suggest either a south extension of the Baltic trough, which in that case may have connected the Arctic and middle Atlantic basins, or a partial submergence of the intercontinental land connection. In either case restriction, if not complete prohibition, of direct littoral migration must have resulted, while current transportation of the floating organisms would have been favored. The Helderbergian invasion of Europe probably followed a similar path except that instead of passing into the Baltic trough, which must have been emerged at this time, it turned southward into newly submerged areas now occupied by resulting lower Devonian deposits. But it is not impossible that this invasion was accomplished by migration from the south Atlantic along the east shore, and thence through the Mediterranean into west central Europe.

Regarding later Paleozoic migrations across the Atlantic, the Neodevonian sea of New York is thought to have been in direct though perhaps not very favorable communication with the German seas of this time by way of the supposed north shore of the middle Atlantic, the New England coast, and finally an opening between Appalachia and Taconia (New Jersey Strait) connecting the Atlantic with the Appalachian troughs and the more inland New York sea. Appalachia and the Antilles at this time probably were united by land connection. The Atlantic Waverlyan, Tennessean, and Pennsylvanian faunas at times followed the same path between Great Britian and the Appalachian Valley, but more commonly, instead of crossing Appalachia, they passed through an opening between the Antilles and the Floridian extremity of Appalachia into the Gulf of Mexico and thence up the Mississippi embayment.

Silurian routes of migration.—Although the pre-Devonian European faunas invaded North America chiefly by following the shores of invading Arctic seas, a number followed the Atlantic route and thence passed through one or more of the openings between the marginal lands. These openings were closed during most of the Niagaran and at other times, but one or another was used by many Ordovician and certain Clinton and Cayugan faunas that are represented in England and western Europe, but not in northern Europe. Somewhat different communication with Europe occurred when these eastern openings were closed. Thus some of the Baltic Silurian genera of crinoids and trilobites seem to have passed freely to the southwestward into the middle Atlantic basin, thence

along the eastern shore of America to the Gulf of Mexico and on through the Mississippi embayment to western Tennessee and northern Arkansas. This migration is indicated by the Saint Clair limestone of northern Arkansas and eastern Oklahoma—a pure crystalline limestone formation corresponding in age to some part of the Clinton of the Appalachian Valley and central New York—in which we find a number of species that are closely allied to Baltic, British, and Bohemian types. Also in the later Brownsport formation of western Tennessee there are many other species having similar relations. Weller, who has given much thought to the Silurian migrations, assumes that the European genera and species in western Tennessee and northern Arkansas reached these localities by simple southward extension of the Arctic invasion.[57] At present I can not accept this view, being convinced that there is no direct stratigraphic connection between the pure limestones of the Saint Clair and Brownsport formations in the south and the dolomitic Silurian limestones in the north. Besides, most of the European genera of crinoids in the southern formations mentioned are different, or are represented by distinct species, from those found in northern Illinois and Wisconsin, which would scarcely be so if they had migrated southwardly across the continent. The distribution of *Scyphocrinus*, which, with its peculiar floating bulb (*Camarocrinus*), is found in late Silurian or early Devonian rocks in Tennessee, Maryland, Great Britain, and Bohemia, but neither in the Baltic region nor in the Silurian dolomites of North America, is very significant in this connection, since it proves that the Atlantic-Gulf of Mexico route was in use during at least a part of Silurian time.

Gulf of Mexico invasions.—Concerning the periodic invasions of North America by the Gulf of Mexico fauna, sufficient positive knowledge has accumulated to justify a number of fairly detailed inferences. As a rule this fauna entered the continental area through the Mississippi embayment, the probable structural connection between southern Appalachia and Llano apparently being frequently submerged. Often the fauna did not spread west of Ozarkia, being confined in these cases to the Ohioan province,[58] a subtriangular region bounded by irregular lines connecting Minnesota, Quebec, and the mouth of the Mississippi River. The lower and upper Stones River, the Lowville, the middle and later Trenton, the middle and later Cincinnatian, the Arnheim Richmondian, the Rochester, the Waldron, the Onondaga, the Hamilton, the Glen Park Kinderhookian, the Spergen, the Saint Louis, and apparently the Saint Genevieve, all of these faunas invaded from the Gulf of Mexico and are confined to one or

[57] Stuart Weller: Journal Geology, vol. vi, pp. 692-703.
[58] U. S. Geological Survey, Prof. Paper No. 24, 1904, note p. 91.

more of the basins in the Ohioan province. The Brassfield ("Ohio Clinton" = earliest Clinton), the Brownsport, the Linden (Helderbergian), the Chattanooga, the Osagian, and most of the Chester faunas likewise invaded through the Mississippi embayment, but differ from the preceding in passing westward by way of the Arkansas Valley, into eastern and sometimes to central Oklahoma. The southern Mesozoic and Tertiary invasions also extend west of the Mississippi embayment, but these extensions are limited to the flat southern border of the continent, including the Great Plains, and did not pass between the Ouachita and Ozark areas.

The Arctic center of dispersal.—The second important center of distribution of early and middle Paleozoic faunas apparently lay in the Arctic basin. From here certain stages of this slowly modifying fauna invaded the Baltic region, the north Atlantic, northeastern and central North America, northwestern Alaska, and the Cordilleran trough of western North America. While the shore life, more especially the gastropods, pelecypods, and the brachiopods, on the American side is, as a rule, very different in specific development from that prevailing on the European side, there is yet a strong similarity in general aspect between the Canadian, Ordovician, and Silurian faunas in the Baltic region and their near contemporaries in certain parts of America. With respect to the middle Silurian faunas this fact, as noted above, has been clearly established by Weller. This similarity is shown particularly by types that either in their early or in later stages of development are adapted to a floating existence, and by others that frequently attach themselves to floating objects—in other words, by species whose paths of migration are not confined to shorelines. These readily migrating types consist chiefly of corals, bryozoa, crinoids, cystids, and ostracods, but they include also certain brachiopods, gastropods, and trilobites. Among the Silurian species in northern Illinois, Iowa, and Wisconsin are some very extraordinary genera of crinoids, corals, and trilobites whose foreign alliances are at once apparent.

The migration of these Silurian genera between the Chicago and Baltic regions probably occurred along the northern shore of the land believed to have connected northwestern Europe with Newfoundland and Labrador during most of Paleozoic time. Southeast of this land, in Europe, is the Baltic trough or basin which received most of its Paleozoic faunas from the Arctic. At times the Baltic trough connected the Arctic and the middle Atlantic basins, permitting, as stated in a preceding paragraph, migrations of Baltic types in a southwestern direction as far as the Mississippi embayment. These migrations, like many preceding, and probably others following them, are supposed to have taken place along the southern shore of the hypothetical land connection.

The Ordovician faunas of the Russian Baltic area so far described have seemed to give little promise for exact correlation with interior American deposits. A few of the trilobites, gastropods, and brachiopods suggest species found in the upper Mississippi Valley, but taken as a whole the Russian faunas of these classes are strangers to the American paleontologist. However, studies of the Russian Ordovician bryozoa now being carried on by Dr. R. S. Bassler are bringing out some surprising and highly interesting results. So far about 70 out of 143 species described from the Decorah shales and the lower members ("Clitambonites" and "Nematopora" beds) of the Prosser limestone in Minnesota have been identified in the Jewe and Wesenberg formations of Russia. Also several Decorah shale ostracods are represented in these Russian formations by closely allied or identical species. It appears, further, that some of the gastropods in the lower part of the Lyckholm may be indistinguishable from species characterizing the top beds ("Fusispira bed") of the Prosser limestone in Minnesota. Finally, American Richmondian faunas are clearly recognized in the upper Lyckholm and the Borkholm.[59]

In discussing the effect of marine currents on the distribution of faunas in continental seas in an earlier part of this paper (pages 365-371) the great extent of some of these Ordovician Arctic invasions of northeastern America is described in sufficient detail. So far as known, the first of these broad invasions occurred in the Black River epoch. The last to reach the United States of those coming in by way of Hudson Bay appears to have been the late middle Silurian Guelph fauna. All of them followed essentially the same pathways and covered in part or whole the same areas. The subsequent middle and late Devonian and Waverlyan invasions by Arctic faunas came in by the northwestern route, and differed thus from the extensive Ordovician and Silurian invasions.

According to evidence now at hand, it is thought highly probable that migration occurred also along the north Russian and Siberian shores between the Baltic region and Alaska. Whether the Paleozoic Arctic migrations were ever quite circumpolar, with free interchange between Alaska and Baffinland, is somewhat doubtful. Certain it is that, so far as known, the Niagaran faunas in Alaska are much less like those in eastern Canada than they are like those in west central and northeastern Europe. However, the Ordovician and Richmondian faunas in Alaska are not very

[59] In connection with the last fact there is to be noted a very interesting coincidence, namely, that in Russia, as in the Mississippi Valley and in the northern and western parts of North America generally, the beds containing the Richmond fauna rest directly on beds holding a rather early Trenton fauna. Where these stratigraphic relations occur in America a well defined unconformity separates the two faunas. Probably a similar unconformity occurs within the Lyckholm.

different from those found in northeastern Canada and Minnesota. Faunas of Canadian age being entirely unknown in northeastern North America, the small early Canadian faunas procured by Mr. E. M. Kindle in Seward peninsula, Alaska, throw no direct light on this question. It should be said, however, that so far as they go these Seward peninsula species are exceedingly suggestive of the Ceratopyge fauna of Sweden.

The Pacific faunas.—The third center of origin and distribution of faunas lay in the great Pacific basin. Considering the whole of geological time and that its waters sometimes spread widely over Asia and Europe on the one side and North America on the other, it is perhaps the most important of the three faunal realms here recognized. In part, it corresponds to Frech's Pacific-American basin,[60] but he includes in this center of distribution the Gulf of Mexico basin, whose fauna I believe to have been as a rule quite distinct from those of the Pacific basin proper. It is true that at certain times of great submergence, as in the Canadian, the Black River, the Richmond, and the late Devonian, the Pacific faunas invaded areas in the Mississippi Valley more commonly occupied by Gulf of Mexico waters, and that, as in the middle Waverlyan, the southern waters occasionally spread farther west than usual. But it is no less true that the Arctic faunas also invaded these areas either by direct southward extension across the North American continent or by means of a Baltic communication with the middle Atlantic, and through this with the Appalachian Valley and the Mississippi embayment.

In fact, the transgressions of the several oceanic waters varied greatly from time to time, certain of the interior continental basins being repeatedly captured and released by first one and then another of the main seas. Because of the bearing of paleogeography on correlation and stratigraphic taxonomy the determination and delineation of these varying successive invasions affords the most important as well as the most interesting of the duties of the modern stratigraphical paleontologist.

The fossil record of the evolution of the Pacific fauna, while very full in certain parts, is in other parts much less complete than that of the Atlantic fauna. Thus the evolution of the Cambrian faunas of the Pacific is more continuously and probably more fully recorded in the enormous deposits of this age in the Cordilleran trough of western North America and in southeastern Asia than is that of either the Atlantic or the Arctic Cambrian faunas.

The ollenellid trilobites probably originated in the Pacific, but as certain species of this genus became very abundant in the Atlantic fauna we

[60] Lethæa Paleozoica, vol. 2, 1897, p. 88.

infer either that the Pacific and the middle Atlantic were in free communication during the lower Cambrian or that such communication occurred in some pre-Cambrian time, and that the Atlantic ollenelli are descendants of some Pacific emigrant of that time. All things considered, the latter inference seems the more probable. Certainly the specific development of the Pacific lower and middle Cambrian faunas is quite distinct from that of the contemporaneous Gulf of Mexico faunas, as expressed in the Appalachian phases, and those of the northern Atlantic as preserved in the corresponding Cambrian sediments in the St. Lawrence region and in western Europe.

Neither the Pacific nor the north middle Atlantic and Arctic Ozarkian faunas are well known, so that their relation to the Gulf of Mexico faunas, which invaded the Mississippi and Appalachian valleys at this time, can not be accurately determined. Of the Canadian faunas recognized in America, the far western (presumably Pacific) facies agrees much better with the Saint Lawrence and northern Appalachian phase than with that of the Gulf of Mexico as developed in the Mississippi Valley and in the southern Appalachian region. Essentially the same geographic affiliations are indicated by the early and middle Ordovician faunas.

It is of interest to note that in both the Canadian and the early Ordovician the Pacific faunas at times invaded as far east as the Arbuckle uplift in central Oklahoma, and that the faunas of these ages on the south side of Ozarkia and in the Mississippi Valley generally are almost entirely distinct from the Pacific facies in Oklahoma. The conviction that a land barrier (Tahlequah axis) separated Oklahoma and Arkansas is forced on us when we consider that while certain Canadian faunas in these two areas contain very few species in common, a large proportion of those found in Oklahoma is comparable or identical with species occurring in the Saint Lawrence Valley and Newfoundland. How these and other Newfoundland faunas got to Oklahoma, except by way of the Arctic and the Pacific, I can not conceive. To bring them there by the more direct and much shorter Atlantic route we must assume either that they crossed the path of the Gulf of Mexico faunas which, according to present correlations, were entering the Mississippi embayment at these times, or that the Gulf fauna was entirely displaced at such times by the Newfoundland fauna. The latter alternatives seem so improbable that I can not admit either at the present time.

The Silurian Pacific fauna is practically unknown. Regarding the Devonian, the record seems very full in the matter of deposits, but less so with respect to the faunas. So far as they go, rather free communica-

tion between the Pacific and the Gulf of Mexico is suggested in Nevada during the early and middle ages of this period. The north Pacific seems also to have been connected with Bohemia (in the middle Devonian), as is indicated by the presence of *Hercynella* in southeastern Alaska. According to present probably somewhat synthetic maps of the late Devonian, it appears that the Nevada basin connected with an Arctic invasion of northwestern North America that extended completely across the continent to the Atlantic at New York city. The communication with the Gulf of Mexico, however, seems to have been, if not entirely abrogated, at least much more limited at this time than it had been in preceding Devonian epochs.

During the Waverlyan and Tennessean the Pacific appears to have been completely separated from the Atlantic except in the early part of the Osage epoch and in the closing Moorefield shale stage of the Meramecian. In the early Pennsylvanian, however, old communications seem to have been reestablished, but toward the close of this period—that is, in the Permian—effective separation again prevailed. About the close of the St. Louis age a Pacific fauna extended by some as yet unknown pathway from Nevada to the northern part of the Oklahoma basin, and thence farther eastward across the Tahlequah axis into northern Arkansas, where it is found in the Spring Creek limestone. Its further progress seems to have been stopped by the Saint Francis axis. However, before the beginning of the Sainte Genevieve this axis was submerged permitting the entrance of the Atlantic fauna and apparently causing a reversal of the trend of migration. This is indicated by the occurrence of closely allied and identical cephalopods in Belgium, in shaly beds just over the Saint Louis in Kentucky, in the Moorefield shale in northern Arkansas, and in Nevada.

DEDUCTIONS BASED ON FAUNAL DISTRIBUTION

The fact that several closely allied or identical species are found in southeastern North America only in Devonian rocks, while in California and Nevada they occur in post-Devonian formations, has long been cited as proving "that the reappearances of older faunas in younger rocks have been due to migrations consequent upon the shifting of physical barriers."[61]

The logical propriety of this deduction is manifest and its truth is established beyond question by many similar occurrences in American

[61] J. P. Smith: Journal Geology, vol. ii, p. 198, and vol. ii, 1894, p. 598.
H. S. Williams: American Journal Science, II Ser., vol. xlix, pp. 94-101.

geology. That a species or genus ceased to exist in some continental basin certainly does not mean that its existence was everywhere terminated at the same time. Such total and approximately simultaneous extinction probably occurred only in the case of locally evolved species whose geographic range was limited to a single continental basin. Other forms, especially those invading from the oceanic basins, not to mention such of these as were common to two or more of the permanent basins, doubtless continued to exist after their local extinction in continental seas. In the meantime physical barriers may have arisen prohibiting their return to resubmerged former habitats, while other barriers may have been let down permitting their subsequent appearance in other continental basins.

Certain faunas, like the Spergen (see pages 298 to 303), are known to have invaded the same general area four or five times, being entirely excluded during long intervening ages. That some earth deformation and sea withdrawal preceded each of these appearances is indicated by slight unconformities and sometimes in addition by clastic deposits. During all this time, however, the fauna continued to live in its permanent habitat, being confined to it when physical conditions were unfavorable, but taking advantage of every opportunity to spread beyond it.

In their permanent and normal habitats the indigenous faunas modified very slowly. It is only when conditions changed in these, and when new faunal elements were introduced, that the inherent tendency to slowly modify was appreciably augmented. Comparing successive faunas in a given section, they often appear to have changed abruptly and wholly at frequent intervals. I do not refer to modifications merely in the local expression of a given fauna, but to changes affecting the fauna as a whole. Unless the plane of change represents a great stratigraphic hiatus, these abrupt transitions, as will be shown presently, may be due to a quite different cause then evolution. It is only by comparing successive invasions from the same oceanic basin that we get anything like a true idea of the character and rate of evolutional modification. The excessive slowness with which the indigenous fauna of such a basin modified under ordinary circumstances is clearly shown when we compare the successive invading stages of the Spergen fauna among themselves, and further with long preceding and succeeding facies of the same. Except for the diagnostic new things that mark each of the Spergen invasions in the Tennessean and early Pottsville rocks of the Mississippi valley, they could not be distinguished. Then, in certain later Pennsylvanian zones we recognize species after species so little changed that only an expert paleontologist can distinguish them from their Spergen ancestors. The aspect of the fauna as a whole has become different, but the change

is conspicuous chiefly because of the new generic and specific types that have been introduced in the meantime from other centers of origin and distribution. Now, if we look up the ancestors of the Spergen species, are they not plainly recognizable in the Hamilton and Onondaga faunas? It was a long time between the Hamilton and the Spergen, but the bryozoa, the brachiopods, and the gastropods in these two formations are similar in general aspect and, indeed, include many closely allied species. The principal difference lies in the species and genera which passed out of existence before the Spergen began. Certainly the two faunas are more closely allied than is the Hamilton to the typical Neodevonian faunas in New York.

The Eopaleozoic faunas traced to the northern middle Atlantic basin afford some striking instances of slow modification. Evidently this was the center of origin of certain Cambrian trilobites and brachiopods whose descendants are unmistakably recognized in faunas that spread from this basin at various times from the middle Cambrian on to the close of the Ordovician. Indeed, one of the trilobite genera, *Agnostus*, maintained apparently uninterrupted existence in this basin to the close of the Ordovician. The same may be said of certain brachiopods, like *Acrotreta* and *Lingulella*. Species of these three genera are found associated in beds belonging well up in the Ordovician in the Appalachian Valley. In the Pacific and Arctic faunas, however, so far as known in America, these genera became extinct with the close of the Cambrian. *Remopleurides*, which is a derivative of the preceding *Holmia* and *Paradoxides*, and *Triarthrus*, evidently descended from some relative of *Ptychoparia* and *Olenus*, are almost constantly met in middle and later Ordovician transgressions of this Atlantic fauna. Although of great value in identifying the source of the invasion, these slowly modifying and generally prolific species and genera have been detrimental rather than helpful in exact age determinations. *Triarthrus becki*, for instance, may be found in any of the shaly beds of the Atlantic Ordovician from the beginning of the Trenton to middle Cincinnatian, while *Agnostus* and *Acrotreta* are no more Cambrian than Ordovician in this basin. It is the new life accompanying the recurrences of these long-lived types that really counts the ages.

A fair conception of the progress of geologic faunal evolution may be gained from detailed comparisons of faunas in areas repeatedly invaded from the same oceanic basin. The purity of the faunal aggregates which have originated and developed in these permanent basins is, of course, being continually, and at times has been very greatly, vitiated by foreign accessions; but during the Paleozoic, at least, the integrity of each was

recognizably maintained through long periods. The idea, which must have been suggested already by preceding remarks on the Spergen fauna, is well illustrated by the Russian Baltic Ordovician section, which embraces between the Glauconite sandstone and the middle part of the Lyckholm the results of six or seven distinct invasions of the Arctic Sea. With the exception of a few evident migrants, chiefly from the north middle Atlantic, this Russian succession of Ordovician faunas strongly suggests periodic exhibits of the faunal evolution in a single faunal province.

The Ordovician formations in central Kentucky, considering only those containing middle Atlantic and Gulf of Mexico faunas, afford a similar illustration, and the contrast between these Kentucky and Russian Ordovician faunas, which have less than 2 per cent of species in common, offers a very striking example of the independence in constituents and development that distinguishes the several centers of faunal origin and distribution. The contrast between the faunas of the Decorah shale, Prosser limestone, and Stewartville dolomite in Iowa and Minnesota, which are believed to have invaded from the Arctic basin, and the Gulf of Mexico faunas in Kentucky, that correspond most nearly in age, is perhaps even more remarkable. Of over 600 species in the former, only about 40, or less than 7 per cent, occur in the latter, and nearly half of these 40 species are recognized as long and wide ranged, perhaps strictly cosmopolitan forms, whose geographic origin is unknown.

The continuous genetic relationship of the successive faunas in sections like the Russian and the Kentucky Ordovician has commonly been supposed to indicate practically uninterrupted sedimentation, even when, as in the case of the Baltic section, the volume of deposits is greatly inferior to that laid down elsewhere in the same period. In fact, however, it implies nothing of the kind. On the contrary, the almost total absence of gradation between the specific stages in the evolution of the genera proves that the transition from one species to the next in its line usually took place in times not represented by deposits in the local sedimentary record. As it is unreasonable to assume that, with continuous opportunity, only the finished specific or varietal stage entered the areas of accessible depositional record, and as the process of mutation, while not uniform in rate, is yet continuous, the conclusion is inevitable that long periods intervened in which deposition was interrupted by sea withdrawal and during which mutation progressed to some later distinguishable stage. Probably mutation was accelerated during these intervening stages of sea withdrawal and consequent change in habitat, but this fact can not greatly reduce the duration of the periods of withdrawal because the suggestion offered

by the evolution of the organisms is strongly supported by stratigraphic data.

The greater breaks in faunal succession noted in local stratigraphic studies are commonly indicative of important interruptions in the sedimentary record. There are, however, other cases in which this is not so. These are most frequently found in areas subject to submergence by waters from different oceanic basins. The Arbuckle, Ozark, and Adirondack uplifts offer very notable examples. Likewise the Appalachian Valley. Comparing, for instance, the successive Ordovician faunas in the vicinity of Mercersburg, Pennsylvania (see pages 325-328), we find that the Stones River fauna is succeeded by a totally different late Chazy fauna. The first invaded through the Mississippi embayment, the second from the north middle Atlantic. The latter was followed by another Gulf fauna—the Lowville—which resembles the first, but is very different from the second. The fourth and fifth faunas have a few forms in common, but both are entirely distinct from all of the preceding faunas. The sixth fauna again is wholly unlike the fourth and fifth. Those invaded from the east; this from the northwest. The seventh fauna, like the fifth, came in from the Atlantic, and is altogether distinct from the intervening sixth fauna. Good illustrations of similar changes in the composition of faunas is given in the discussion of currents in the continental seas (pages 367 to 371).

EFFECT OF EXPANSION AND RESTRICTION OF CONTINENTAL SEAS ON EVOLUTION

I can not permit this opportunity to pass without expressing my conviction that the prevalence of so-called expansional evolution is overestimated in certain quarters. The idea advanced by Chamberlin of "expansional evolution of shallow water life . . . in broad epicontinental seas of nearly uniform depth,"[62] seems a plausible conception, but so far as I can learn it is not being generally accepted by practical paleontologists who should naturally be the best judge of its value. It is true that species which have migrated from Europe and Asia to America, or *vice versa,* have rather commonly sustained sufficient modification to be distinguishable. It is probably true also that some expansional evolution took place in the newly invaded continental seas. Yet, after all, when we note the distribution of the fossil species in America, and when we compare the near and distant occurrences that we may reasonably regard as geologically contemporaneous, the facts point strongly to the conclu-

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[62] T. C. Chamberlin: A systematic source of evolution of provincial faunas. Journal Geology, vol. vi, 1898, pp. 597-609.

sion that the modification was accomplished in transit between the continents or before the invasion of the latter, rather than within the median continental seas themselves. As to the expansional evolution within these interior seas, it seems to me this was never the important factor in the evolution of marine faunas that it is believed to be by Chamberlin and other recent writers, none of whom has made a specialty of the study of fossil faunas.

The Burlington crinoid fauna and the bryozoan and other faunas in the Maysville formations about Cincinnati afford perhaps as good examples of Paleozoic expansional evolution as can be cited. But even in these cases we may well inquire if it is not rather a matter of favorable habitat and preservation, or even more of exceptional opportunity and effort to make full collections than of prolific evolution? Certainly a very strong nucleus of the Burlington crinoid fauna existed in the preceding Kinderhook and Fern Glen faunas, while the lower Maysville fauna is merely a later phase of the late Trenton Catheys fauna which invaded the same regions long before. In the latter case the change most certainly did not take place within the continental seas, since the fauna is almost entirely absent in the otherwise highly fossiliferous intervening formations.

The apparently local faunal distinctions which probably suggested the idea of expansional evolution in geologic times, as, for instance, the difference in the Niagaran faunas in Wisconsin, New York, and Tennessee, or in the middle Ordovician faunas in the same three States, are due to other causes than merely local peculiarities in development of contemporaneous faunas. As shown in discussing the "early Trenton" deposits and faunas (pages 367-373) and those of the Niagaran (pages 558-561), these differences are due chiefly to the fact that the several faunas invaded the continents from different oceanic basins, the Wisconsin faunas in question being of Arctic origin, the Tennessee faunas came in from the Gulf of Mexico, and the New York in part from the Atlantic. Moreover, most of these contrasted faunal expressions, which have been supposed to be contemporaneous, are in fact not of the same ages in the three areas. These facts, of course, weaken the argument very materially, if indeed they do not completely vitiate it.

Another belief that helped in framing the suggestion of expansional evolution is that great intermingling of previously distinct faunas occurred at times of exceptional submergence of continents. However, detailed analysis of the faunas, on which this belief is chiefly based, proves, as is briefly outlined in preceding parts of this work (pages 370 and 494), that commonly the supposition is quite groundless. As shown,

the early Trenton submergence, which is often cited as the greatest known, comprises several distinct submergences, differing in direction of invasion and in the composition of the faunas that were brought in with the different waters. The fact of greatest significance brought out by study of numerous sections containing middle Ordovician formations is that the several faunas, even where overlap of northern and southern facies occurs, remain perfectly distinct. Although published lists of Mohawkian species, say in Kentucky and Minnesota, include, besides the quasi-cosmopolitan forms, many other species common to both areas, it is found that nearly all of the latter are confined to formations or faunal zones that extend either northward from Kentucky to Minnesota (the Lowville) or southwardly from Minnesota to Kentucky. True intermingling of faunules characterizing the Mohawkian in these two States does not occur. In some cases intermingling was impossible because beds found in either one of these States are not represented by deposits in the other, while in the case of the remaining, possibly contemporaneous faunas, intermingling failed because the submergence was insufficient to accomplish confluence of the northern and southern basins.

As may be gathered from various comments in this work on the Niagaran submergences (see pages 485 and 558), the facts in this case are essentially as in the preceding Mohawkian invasions. It is somewhat different, however, in the case of the late Hamilton submergence, during which some intermingling of southern and western faunas occurred in the vicinity of Lake Michigan. But even here there is little or nothing to suggest that this intermingling resulted in expansional evolution.

Organic evolution being largely dependent on physical conditions which are ever changing, and thus doubtless a continuous process, is less a matter of inherency and volition than of necessity. Naturally, then, organic mutation as a rule is in proportion to the degree of diversity in physical condition prevailing in a given time and given region. The stresses incident to the withdrawal of waters from continental areas, the struggle for existence under the resulting restriction of favorable habitat: these obviously might well stimulate the inherent tendency to modify. But the Paleozoic continental basins, which when occupied by large and varied faunas, as is established by the unanimous testimony of all criteria bearing on the question, were much more uniform than the oceanic basins in depth and most other physical conditions, except temperature of waters, implied by the term environment. In these basins it would seem that organic evolution was more likely to be retarded than stimulated, and that the changes noted in their faunas are to be ascribed chiefly to other causes than evolution in the basins themselves.

This assertion may not harmonize with theoretic considerations respecting organic evolution, but that is of little consequence so long as it is in accord with observed facts concerning the distribution and integrity of fossil species. I venture to say that the Cretaceous and Tertiary faunas of our coastal regions, which certainly were favored with very considerable expansion of shallow-water conditions as compared with the present stage, do not bear out the idea of expansional evolution. Neither can I find any convincing indication of unusually stimulated evolution in any of the Paleozoic submergences of interior continental depressions. Nor have I found that local or provincial evolution increased with the advance of an invading fauna.

While it is true that many species occur at Cincinnati that are unknown in corresponding beds in middle Tennessee, the fact may still mean no more than that they have not yet been found there. Many species again are very common at one locality and very rare or quite absent at another, but this probably has nothing to do with their evolutional origin. On the contrary, all species are more or less local in distribution, especially if we consider the matter of abundance of individuals. The discovery of previously unknown species, or of new geographic occurrences, is a matter of daily experience to the energetic collector. Finally, we find species at Chicago that are either the same as, or close allies of, Baltic types. Though they may not have been found in the intermediate areas, no one will doubt that the path of migration passed over certain as yet unworked parts of these areas. If every outcrop of Silurian rocks in Canada could be searched like a Chicago quarry the apparent anomalies in geographic distribution of northern Silurian species would be mostly accounted for.

MUTATION OF FOSSIL MARINE FAUNAS ACCOMPLISHED BEFORE THEY INVADED CONTINENTAL SEAS

As a result of my investigations I believe the faunas of the continental seas consist almost entirely of organisms that have periodically and very frequently migrated from their permanent oceanic habitats into these inland seas. The organisms passed into and about in these basins when and where conditions were favorable for their existence, and they remained out when the conditions were not favorable. But on account of their shallowness even slight climatic changes effected such extremes in the waters of these inland basins that the faunas were often exterminated locally. The supply, however, was inexhaustible and ever ready to take advantage of opportunities to replenish the shortage, and there was ample time for every purpose. New things came in with each return of the fauna, but many of the preceding tenants remained out forever or

returned only after long intervals of local or general absence in a basin or province. As for the new occurrences, which constitute the principal element of difference by which the paleontologist distinguishes the successive faunules: these have very often no genetic relationship to their predecessors in the same locality or basin, even when there is no appreciable change in sea-bottom or other environmental features. Evidently the new forms came in "ready made."

That the faunas of the continental seas were not subject to stimulated modification, either local or general, within the seas themselves, as they should have been if expansion of favorable habitat had been an important factor in their evolution, seems readily demonstrable. If it had been then the successive faunules in a single or in contiguous formations must have been developed out of each other. In fact, however, this is true of only a small percentage of the species, and those of which this may be said are usually derivatives of the vigorous, long-lived species that are dominant through considerable vertical and geographic ranges and which therefore are correspondingly inexact in their time relations. On account of their wide range in time and space the successive appearances of mutations of such species is as readily accounted for under the view of frequent, distinct invasions or replenishments as under the supposition of continuous existence within the continental basins.

The determination of the direction and extent of marine currents within the continental basins has an important bearing on this problem. Convincing evidence is presented by the distribution of certain bottom-dwelling organisms which depend on currents for the expansion of their geographic range. The corals and bryozoa probably offer the most competent data. As most of these assume sessile habits in maturity but are free and subject to transportation by shore currents in their larval stages it is at once suggested that their range in the continental basins must be limited by the extent of the marine current to which they owe their occasional migrations from the oceanic to the continental seas. Many bryozoan and coral faunas are known in the Ordovician, Silurian, and Devonian rocks of southern North America. Most of these invaded the continental seas from the south through the Mississippi embayment, and in a number of instances the path and extent of the several invasions has been satisfactorily determined. In all cases the numerical representation of the two classes of fossils, both as to species and individuals, is greatest at the localities nearest the point of ingress. Beyond these localities their number decreases sometimes rapidly, at other times slowly, the layers in which they occur become fewer, and the percentage of species found at the more inland stations that are unknown

in the proximal parts of the path of invasion is always so small that it is reasonably ascribable to fortuitous circumstances in original distribution and collecting. Evidently, then, the corals and bryozoa advanced only so far as the currents entering from the Gulf of Mexico maintained their efficiency as distributing agents. The truth and great significance of this statement will be apparent when we add that beyond the first considerable break in the continuity of their occurrence they, and indeed all representatives of their classes, are seen no more. The conclusion therefore is inevitable that the evolution of the corals and bryozoa was practically accomplished in the oceanic basins and their further mutation in the continental seas correspondingly insignificant.

Continuing the argument, if expansional evolution had prevailed, and if we do not confine the process of evolution to saltation of specific grade, the rocks should be filled with intergrading links. But do we find anything like this in the fossil faunas? A well known occurrence that might be said to fairly satisfy the requirement is that of the fresh-water shells in the upper Miocene at Steinheim, Germany. Except for the uncertainty attending the preservation of land deposits of any sort, such occurrences would probably be common enough since, on account of their relatively strenuous existence, the shell faunas of lakes and tributary streams are not only more liable to rapid mutation, but they are also much less sensitive to temperature changes than marine shells. But, aside from such considerations it is to be observed that under ordinary circumstances minor organic mutation in these unstable land waters took place within them and not, as I believe of the marine faunas of the continental seas, in the relatively permanent oceanic basins.

In the case of the Paleozoic marine faunas in the continental seas the above query must be answered with an emphatic no. If the deposits of these seas contained anything like the number of intergrading mutations that might reasonably be expected in the evolution of species the paleontologist's work in stratigraphic correlation would be hopeless. There are individual peculiarities in plenty, some of them suggesting reversion while others may be anticipatory; and there are local varieties; but altogether these departures from type rarely if ever constitute a satisfactorily complete transition from one to another species. We find also many species and varieties that are intermediate in character between other species, and the position of these in the evolution of a genus or group of species is more or less certainly determinable; but almost invariably we deal with the nearly finished product of a process of mutation that was begun and established before the new phase invaded areas now accessible to the student of fossil faunas. Apparently the mutations

were practically accomplished in the oceanic basins. That they were occasioned by stimulation of inherent tendencies under the stress of restricted habitat and consequent strenuous existence seems a most reasonable conception.

The truth of the statements in the foregoing paragraph can not fail to impress those who have made a detailed study of the rocks and fossil faunas in the vicinity of Cincinnati. In this celebrated section there is scarcely one of 600 or 700 feet of deposits that does not contain an abundance of excellently preserved organic remains. Among the millions of good specimens there is never any question as to the species or variety to which an individual belongs. When as a boy and young man I strove, with a zeal and devotion that bore other fruit, to prove the theory of evolution by the fossils, this fact of almost unwavering fidelity to type displayed by my collections was my despair. And it continued to be an inexplicable fact until the thoughts above expressed came, first faintly and obscurely, then more and more definitely into my mind.

EXAMPLES OF LOCALIZATION IN DEVELOPMENT OF PALEOZOIC FAUNAS

Some remarkable differences in composition are noted in comparing the accessible Pealeozoic faunas of the Atlantic, Arctic, and Pacific realms. Of sponges, the Lithistida are abundant in the Caribbean-Gulf of Mexico faunas which invaded the Mississippi embayment in Canadian, Ordovician, and Silurian times while the Hexactinellida are rare. The latter on the contrary, are common in the Canadian and Ordovician Pacific and northern Atlantic faunas, in which the Lithistida are relatively few. The true corals, which appear for the first time in the Ordovician, seem to have originated either in the Atlantic or the Arctic. They are unknown in Pacific faunas of this period, but in the Silurian the class attained cosmopolitan distribution, the same genera, and it is said even the same species, being recognized in Arctic, Atlantic, and southern Pacific areas. The greatest development of the corals in this period occurred in the Baltic region and in the lower Mississippi Valley. As practically all the genera and some of the species of the latter area are found in England and Sweden (Gothland), it is thought probable that the Baltic or the Arctic basin, rather than the southern Atlantic, was the center of dispersal. This view finds additional support in the fact that certain peculiar genera, like *Goniophyllum* and *Calostylis,* invaded America from the north as far as Iowa and Illinois but, so far as known, failed to join the Gulf of Mexico invaders.

Of the echinoderms, a few cystid-like forms have been found in the

Cambrian. Undoubted cystids are imperfectly known in Ozarkian and Canadian rocks. These remains occur in both Atlantic and Pacific deposits. In the Ordovician but few true cystids are known in Gulf of Mexico faunas, but they became very abundant in the Arctic waters of this age. The crinoids, however, seem to have originated during the early Ordovician in the southern middle Atlantic, where the dominant types, as expressed in the invading Gulf faunas of this age are Dendrocrinidae, Heterocrinidae, and Glyptocrinidae. These spread rapidly into the northern middle Atlantic, which became an important center of crinoid development and dispersal, and from here, via the Baltic, into the Arctic basin. The dominant Ordovician crinoids in the northern Atlantic are Dendrocrinidae, Carabocrinidae, Hybocrinidae, and Rhodocrinidae. During the Silurian the Gothland crinoids, like the corals, spread freely through the Arctic and then southward in America to northern Illinois. They extended also southward into England, where a slightly different development obtained, and thence into the Atlantic to the Gulf of Mexico and the Mississippi embayment. All the succeeding Paleozoic crinoid faunas, so far as known, originated in and spread from the Atlantic basins. Regarding the Pacific realm it is an astonishing fact that, excepting a few Indian and Australian species, no good Paleozoic crinoid has been described from it.[63] In fact all echinoderms seem to have been rare in this faunal realm during the Paleozoic.

The bryozoa seem to have originated in the south Atlantic or Caribbean Sea during the Canadian period, a species of *Nicholsonella* being exceedingly abundant in rocks of this age in northern Arkansas. Beginning with the Ordovician they spread rapidly northward to the Baltic and Arctic regions. In the middle Paleozoic ages the bryozoa in these two, northern and southern, basins developed along somewhat different lines. In deposits of Pacific waters the class is almost entirely unknown until after the Devonian when its genera had become decidedly cosmopolitan.

The brachiopods began early in all of the major oceanic basins. It is only in the matter of genera and minor groups of species that notable geographic limitations are observable. Thus *Porambonites* and *Trimerella* seem to be confined to Arctic waters, *Leptobolus, Hebertella,* and *Rensselaeria* to Atlantic, and *Richtofenia* to Pacific. In the Ordovician and Silurian many genera of brachiopods were common to the Atlantic and Arctic basins that have not been found in Pacific deposits. Toward

[63] The Waverlyan crinoids found in Montana and New Mexico doubtless invaded these areas from the Gulf of Mexico.

the close of the Paleozoic, however, the Arctic brachiopods became as much or more like the Pacific types.

But few of the described early and middle Paleozoic pelecypods belong to the Pacific realm. By far the most of these shells originated in the middle Atlantic from which they spread into the continental seas of southeast North America and Europe. In later Paleozoic ages, however, a considerable development of the class occurred in the Pacific faunas. Some Cambrian fossils have been referred to the Pelecypoda, but all of these that I have seen, and concerning which there is no question as to their Cambrian age, have proved to be bivalved crustacea. The oldest unquestionable pelecypods known are found in the Saint Peter sandstone in the Mississippi Valley. This suggests the Caribbean sea or the south Atlantic as the probable center of origin of the class. The first gastropods having invaded the North American continent from the same direction long before suggests further that the pelecypods were derived from the primitive bilaterally symmetrical "patelloid" types of that class.

The oldest, in everywise unquestionable, fossil record of the coiled gastropods[64] and of cephalopods is found in the Ozarkian rocks. In fact these classes constitute the most important parts of the middle and later faunas of this period as developed in the Mississippi Valley. As but few species of these classes are found elsewhere in rocks of this age, it is assumed that the gastropods and cephalopods originated in oceanic basins to the south of the Mississippi embayment, that is in the Gulf of Mexico, Caribbean Sea or South Atlantic. From there they spread to the north and west, attaining before the close of the Canadian period rather general distribution in the continental seas of North America. However, judging from the Baltic section, they seem not to have reached the European side of the Arctic until well into the Ordovician. About the same time, or perhaps in the somewhat later Black River epoch, certain types of cephalopods, like *Gonioceras* and *Actinoceras,* spread from the Arctic into the Pacific. The development of the Eopaleozoic gastropods and cephalopods, also the pelecypods, in the Bohemian-Mediterranean province, seems to have been largely independent. Possibly they were derived from Pacific ancestors, but the major part more likely originated in preceding south Atlantic connections. In the Neopaleozoic and Pennsylvanian ages both the gastropods and the cephalopods developed along similar lines in the three provinces of the Atlantic realm. Their Arctic

[64] A few small, unsymmetrically involute shells, that resemble *Platyceras* and *Cyrtolites* and which may possibly be true Gastropoda, occur in the Lower Cambrian in Nova Scotia and Newfoundland. The same type of shell extends up into the Ozarkian. A species of the latter was described by Walcott as *Platyceras minutissimum.*

history in these ages is practically unknown; and their Neopaleozoic development in the Pacific realm likewise is obscure. But the Pennsylvanian representatives of both classes in the Pacific realm are much like those in the Atlantic. Of course there are many more or less peculiar local developments, as in the Guadalupian of Texas, the Salt Range in India, the Urals in Russia, and Sicily in the Mediterranean, but these are connected by enough of cosmopolitan genera so that the general aspect of these faunas is not greatly unlike those prevailing during this age in the Atlantic basin.

The crustacea, as is indicated by the great development of trilobites and phyllopods in the Cambrian deposits of western North America, probably originated in the Pacific realm long before the Eopaleozoic. The known Cambrian phyllopods are easily separable into (1) the north middle Atlantic and Baltic types, found in the northern Appalachian and the Saint Lawrence troughs in America and the British Isles and the Swedish Baltic region in Europe, and (2) the Pacific types found in the Cordilleran region of western North America. However, several species found in China are closely allied to Saint Lawrence forms. Regarding the trilobites, the Cambrian types divide up much the same as the phyllopods in origin and distribution of genetically related species and genera. Essentially the same geographic distribution of the trilobites continued to the close of the Ordovician, except that the communication between the Saint Lawrence, Baltic, and Arctic faunas seems to have grown more intimate, and that at times the south Atlantic fauna mingled with that of the Pacific or simply extended into areas commonly occupied by the latter. In the Ozarkian, for instance, a distinct trilobite facies, distinguished especially by *Dikelocephalus* and believed to have been developed in the Gulf of Mexico and Caribbean basins, invaded the Ohioan province to Quebec on the one hand, and by way of the Iowan basin and the Great Basin, to Nevada, on the other. The upper Cambrian (Saint Croix) invasion of this southern Atlantic fauna differed in that it did not extend beyond the Virginias in the Cumberland basin and in that it did extend southward (as well as northwestward) from north Arkansas through Oklahoma and New Mexico to Arizona. Whether this fauna in either case actually mingled with a true Pacific fauna in Nevada seems questionable. Except in the Mississippi Valley proper and in the southern Appalachian region, the Canadian deposits in America frequently contain *Asaphus*-like tribolites. So far as known, this genus does not occur in the succeeding Ordovician formations in America, except in Newfoundland, but it is very common in the Baltic deposits of this

period. In the American Ordovician its place is rather generally taken by the related genus *Isotelus,* which, on the other hand, is rare in the Baltic region. Throughout the Eopaleozoic the development of the trilobites in central Europe was distinct from that going on in the Baltic region. In fact, the differences between the trilobites of these two regions is greater than is found in comparing the species in either with those occurring in the eastern American provinces. In later Paleozoic ages the trilobite genera seem to have become more cosmopolitan, and hence less distinct in regional development.

The ostracoda are met with for the first time in the Canadian limestone formations in North America. The oldest types are typical Leperditiidæ. As they occur in Nevada and in the Champlain and Ottawa basins as well as in Tennessee, Arkansas, and Oklahoma, the locus of their origin is somewhat uncertain. However, as the southern occurrences seem to be older than the others, I am inclined to place it in the Gulf of Mexico and Caribbean basins rather than in the Pacific or the Arctic. The smaller ostracods, which began rather late in the Canadian, attained a high state of development in the Ordovician and maintained their importance to the present time, are almost world-wide in distribution. Taken as a whole, this group of crustaceans seems to have enjoyed unusual facilities for dispersal. Of course, some localization in development occurred during the Paleozoic, especially in the Silurian period. But most of these geographically restricted types constitute comparatively small genera. Among large genera the case of *Beyrichia* is perhaps the most noteworthy. This genus is extraordinarily developed in the Silurian rocks of Sweden and England, but is rather rare elsewhere. A few species are found in Maine and the Appalachian Valley and one in the Waldron shale in Indiana. Another case is *Kloedenella,* which is extremely prolific in the Appalachian Valley, but rather rare elsewhere.

Principles of stratigraphic Correlations

GENERAL DISCUSSION OF THE PRINCIPLES

The principles or methods of stratigraphic correlation may be divided into two unequal groups: (1) those showing positive relations, and (2) those implying deductive reasoning. Under the first head comes

(*a*) Superposition.—The order in which the strata were laid down is the very foundation of geologic chronology. As determined in undisturbed regions, it affords positive, though more or less incomplete, evidence

of the succession of the lithological units and of the fossil faunas and floras entombed in them.

(*b*) Geographic continuity.—This is established by tracing the beds by actual outcrop from point to point, or by reasonable inference from data obtained from deep wells in undisturbed areas.

Under the second head we place correlation by

(*a*) Similarity of organic remains.

(*b*) Similarity of lithologic characters, including similarity in genesis or homogeny.

(*c*) Evidence of deformative movements of the lithosphere.

(*d*) Evidence of gradual submergence, usually indicated by stratigraphic overlaps and ascribed to various causes, such as sea-filling, possible equatorial heaping of waters, and slow adjustment to gravitational stresses.

In the further discussion of these methods those of the first group, namely, superposition and geographic continuity, might be passed over as too obvious to require detailed explanation. All will understand that relations established by superposition go no farther than the facts brought out by individual sections. These may express a complete sedimentary record for the part of the stratigraphic column shown in them; or they may be more or less incomplete, the locally absent elements being established by comparison with other sections in which they are present. The completion of the record, or rather of so much of it as is accessible, may involve all the other methods. As to the areal continuity of a lithologic unit, this of itself does not establish contemporaneity of the geographically separated parts of the unit. This is true especially of the overlapping initial deposits (usually sandstones) of an advancing sea; but the range of time included in known examples is, not as great as is thought by some. As the practical application of this method of correlation, as also that based on stratigraphic overlap, is closely associated with and must be checked by certain deductive methods, its further discussion may well be made incidental to matter more strictly referred to under the headings "Correlation by lithological similarity" and "Correlation by evidence of diastrophic movements."

CORRELATION BY MEANS OF ORGANIC REMAINS

General discussion.—Correlation by means of fossils is universally accepted. It is also quite generally believed that fossil evidence is relatively the most competent of the several classes of evidence now employed in correlation. That the rank of organic evidence is of the highest can not be

denied. On the other hand it must be admitted that this evidence, like any other, is liable to misinterpretation. The fault lies not with the fossils—they are always right—but with us. Local faunal associations, whether fossil or living, are but imperfect snapshots of a long, continuous, and infinitely complex process of mutation; and the exact determination of the relations of the various pictures to each other becomes a relatively simple matter only when the general plan of faunal migration has been worked out. This plan even is not uniform in its operation, but changes from time to time with the varying movements of the land and sea. To meet this difficulty the paleontologist must be wary and unremittingly on the lookout for exceptions to the accepted rules. He must also realize that all rules are but temporary, and that the exceptions may presently reverse the rules. This may seem discouraging to the paleontologist, but after all there is no cause for misgivings as to the present and ultimate value of organic evidence in correlation. Though the working plans of yesterday are riddled with exceptions today and those of today may be similarly modified tomorrow, the comforting fact yet remains that we are steadily progressing.

I have strong convictions respecting the great possibilities of correlation by a judicious application of organic criteria. Their greatest value in this connection arises from the demonstrable fact that, as a rule, the migration, and to a considerable extent also the evolution, of species, however slow, is yet relatively rapid as compared to the inconceivable length of geologic time. As to marine faunas, with which the student of Paleozoic stratigraphy is chiefly concerned, their migrations, when not prohibited by physical barriers, usually proceeded with such rapidity that their progress can not be expressed in recognizable units of the geologic time scale. Hence, unquestionable correlations by fossil evidence, fully checked by physical criteria, may be said to establish, so far as the practical purposes of geology are concerned, the essential contemporaneity of the beds so identified. The trend of the whole mass of correlation data in hand gives unqualified support to this contention. Its probability is raised almost to complete demonstration by such observed instances of recent migration of species as that of *Littorina littorea* on the Atlantic coast (see page 295).

Summary statement of principles.—With the citation of a few examples the principles of correlation by fossils may be summarily stated as follows:

(1) Systematic paleontology.—*Systematic paleontology without a stratigraphic basis is regarded as an absurdity.*

(2) "Matching" of species and genera.—*This is the first step in correlation by fossils.* The degree of similarity exhibited by geographically separated faunas is usually proportionate to their respective ages. If great, then the evidence is provisionally accepted as indicative of essential contemporaneity. But the result of mere matching of faunas, however close, is, of itself, never conclusive. For instance, there is a fauna of about 80 species in the basal part of the Liberty Hall limestone in west central Virginia. The fauna includes species of several genera usually regarded in America as Cambrian. A much larger proportion of the fauna consists of species closely allied to or identical with Chazy types. Others are unknown elsewhere. Finally, there are some species whose evidence is exact and fully in accord with the stratigraphic evidence on which the bed is determined to be younger than Chazy and older than Trenton. Obviously, simple matching in this case might lead to serious error. It shows, also, that careful discrimination of the faunal evidence and elimination of the non-essential factors are sometimes required and always desirable before reaching final conclusions. This is especially necessary in cases of reappearing faunas like the Spergen. The species of this fauna have a definite zonal value only in the Spergen zone itself. Hence, in correlating such later horizons as the Sainte Genevieve and the Tribune, the Spergen constituents of their respective faunas must be eliminated from the list of characteristic species and reliance confined to the remaining more exactly diagnostic forms.

(3) Dominant species.—*Individual dominance of species is not a reliable test of the chronological significance of local faunal aggregates,* because (*a*) the list of dominant species necessarily includes the relatively vigorous types which, under average conditions, are likely to be more adaptable, longer lived, and correspondingly less definite in their time relations than their weaker and more sensitive associates; and (*b*) the numerical representation of any and all organisms varies from place to place according to local changes in environment, and probably on account of other more fortuitous circumstances, so that a given species may be found at one locality in sufficient abundance to place it at the head of the list of dominant fossils, while its rarity in beds of exactly the same age at another place may exclude it entirely.

The first case is illustrated by such vigorous, long-ranging, though doubtless too loosely conceived species as *Leptæna rhomboidalis, Rafinesquina alternata, Plectambonites sericeus, Dalmanella testudinaria, Platystrophia biforata, Isotelus gigas* and *Calymene senaria.* All of these are found at intervals through long geological terms, and when they

occur at all it is usually in sufficient abundance to insure high rank in the matter of dominance.

The numerically variable distribution of two varieties of *Platystrophia biforata* or *lynx* and of *Orthorhyncula linneyi* may sufficiently illustrate the second case. Thus, there are two well defined zones in the hills back of Cincinnati, Ohio, and Madison, Indiana, in which large varieties of *Platystrophia* are found. The upper one (Mount Auburn bed), at the top of the McMillan formation, contains the short-hinged variety, while the lower zone, in the upper part of the Fairview limestone, is marked by the long-hinged, quadrangular variety. Now, at Cincinnati the upper variety is exceedingly abundant, while the lower form is comparatively rare. At Madison, on the contrary, the lower variety is found by the thousand, while the short-hinged, later variety is far less abundant. Regarding *Orthorhyncula linneyi*, this is a common and highly characteristic fossil of the upper part of the Fairview limestone in central Kentucky south of Kentucky river. At Cincinnati, however, this fossil is exceedingly rare, though many of its principal associates in central Kentucky are common enough.

The Silurian and Devonian coral faunas offer some very notable instances of irregular areal distribution. This is true especially of the reef builders, whose colonies, being confined to waters of certain depths and very slightly varying temperatures, vary rapidly in thickness and may pinch out in short distances. Broader differences in distribution of corals and other organic types, as for instance in the Onondaga fauna, as developed in southwestern Illinois on the one side and in central Kentucky and New York on the other, probably are due to another circumstance, namely, the latter areas are near the southeast and northeast shores of the Onondaga sea, while western Illinois is near its southwestern shore. The corals invading the basin from the middle Atlantic by way of the Mississippi embayment probably followed the most natural route, which would be the east shore. The relative paucity of the coral element in the fauna of the Grand Tower limestone is thus explained.

(4) True guide fossils.—*A single species, or preferably two or three constantly associated, rare or common species, may be of greater practical utility and often of more exact value in correlation than all the remainder of a large fauna.* For instance, after making sure that the beds of some Appalachian exposure are of Cincinnatian age, I should depend more on *Orthorhyncula linneyi* in deciding that the layers containing this fossil are strictly equivalent to the upper part of the Fairview limestone at Cincinnati than on perhaps fifty other species that may be associated

with it. Again, but this time referring to a larger unit, the discovery of *Rhynchotrema capax,* or *Rhombotrypa quadrata,* or *Sceptropora facula,* would be deemed sufficient evidence on which to base an identification of Richmondian deposits. It is to be said, however, that while these fossils seem to be diagnostic of the Richmondian over the whole northern hemisphere, none of the three is very useful in distinguishing the several zones of the series. Other species of more limited geographic range are used for this purpose.

Doubtless most of the larger divisions of the time scale and probably many of the inferior units are identifiable by equally trustworthy guide fossils. Their recognition and final selection is a matter solely of acquired detailed knowledge and extensive tests in the field. Obviously, their practical value in correlation is greatest when they are striking objects, easily recognized and common enough to be quickly found when needed.

(5) Sequence of life zones.—*The sequence of minor but well defined life zones, when found to agree in widely separated localities, is to be regarded as highly significant in establishing the essential contemporaneity of the respective zones.* The value of the principle is enhanced by the fact that the identification of each zone checks the correlation of the other zones. However, on account of the oscillating character of continental seas, the application of this principle, except in broad correlations, is necessarily limited to sections within the same province or basin. Its chief source of difficulty arises from the same cause, namely, on account of differential movements (many are described in the first chapter of this part) the sequence of beds and fossil zones is not exactly the same in any two areas of uplift, nor even on opposite sides of the same "dome." Bearing these frequent local imperfections of the record in mind, the principle of similarity in sequence is very useful in corroborating and checking correlations of the individual zones.

A good example is found in comparing the successive changes in the Eden-Maysville fauna at Cincinnati with those in the Utica-Lorraine fauna in New York. The well defined faunal zones in the former section are more easily recognized in the latter than I believed before making a personal field study of both. Perhaps the best example is that of the Ordovician, Silurian, and Devonian life succession in the Cincinnati and Nashville uplifts. The lithological aspect of this instance is discussed on page 526.

(The frequently abrupt passage from one to another of these life zones, whether their faunas are new or recurrent, is thought to indicate either a change in the contributing oceanic basin or withdrawal of the

continental sea itself. On resubmergence either the same oceanic basin at once resumed its contribution of life, or oscillation may have changed the geographic pattern so that the new sea drew its fauna from an altogether different source. In the former case the life break may appear insignificant; in the latter it is proportionately much greater than the time break. The conditions referred to are at the basis of the following principle.)

(6) Varying time values of faunal breaks.—*The relative magnitude of a faunal break is often widely disproportionate to the time break.* One may be either greater or smaller than the other when measured according to an hypothetical standard. Thus a total change may be occasioned by superposition of an Arctic or a Pacific fauna or a north Atlantic fauna on a Gulf of Mexico fauna, and yet the time value of the break be relatively insignificant. Of many examples I may cite the abrupt and total change in faunas encountered in passing from the upper Stones River into the basal, upper Chazy, member of the Chambersburg limestone near Mercersburg, Pennsylvania, and from this again into the overlying Lowville member. That the time value of these breaks is not in due proportion to the faunal change is shown by the much smaller differences noted in comparing the faunas of the Stones River, which underlies the upper Chazy, and that of the Lowville, which overlies it. (See also pages 545 and 554.) As for the cause of the differences in value it is found in the fact that whereas the upper Chazy fauna is north Atlantic in origin the others migrated from the Gulf of Mexico. A case of like significance is seen in the Curdsville limestone, which contains a large northern fauna that is intercalated in the midst of very different southern faunas.

On the other hand, the difference between two immediately superposed faunas may appear insignificant, although the time break between the two is really of very considerable magnitude. The slight difference between the upper Stones River and Lowville faunas just mentioned serves well to illustrate the idea. In fact, when, as frequently happens, these two also lithologically similar formations are in contact it is often difficult to find the plane of separation. And yet the hiatus, as shown in east Tennessee, represents pure limestone, shale and sandstone deposition aggregating thousands of feet in thickness. (See pages 554 to 557.) It is well illustrated also by the stratigraphic relations of the closely simulating Catheys and Leiper faunas in middle Tennessee, where the two commonly are in contact and require great care in their separation. However, in central Kentucky and in the vicinity of Cincinnati the Catheys formation is at or near the summit of the Mohawkian and is followed by 100 to 300 feet of

Eden shale and the lower 50 to 100 feet of the Fairview limestone before the upper beds of the latter, in which the fauna is most like that of the Catheys, are reached. A still greater value for the interval is suggested by sections in the Appalachian Valley, where it sufficed for the deposition of nearly 1,500 feet of calcareous shale and sandstone. A third example is found in the Spergen and middle Sainte Genevieve (Fredonia) oolites, which contain very similar faunas and are in contact on Monte Sano, near Huntsville, Alabama, but separated by approximately 400 feet of Saint Louis and lower Sainte Genevieve limestones in the Mississippi Valley below Saint Louis. In all three of these cases it is to be further observed that the intercalated beds do not fully account for the stratigraphic break so slightly indicated by the fossils, since even where the intervening beds are thickest there is still evidence of discontinuity of sedimentation at their bases and perhaps also at the top.

(7) Barriers prohibiting intermingling of distinct faunas.—*The mere fact that marine faunas in adjacent areas, whether in lithologically similar or dissimilar strata, are totally distinct is not of itself conclusive evidence of great difference in age.* Such differences may be due to various kinds of barriers prohibiting intermingling of faunas invading continental seas from distinct oceanic basins, or possibly to currents of varying temperatures. Instances of such conditions are suggested in many parts of the country, notably in the Appalachian Valley, where certain nearly contemporaneous faunas like those of the Levis shales and of some corresponding limestone of the Beekmantown, and those of the Normanskill and Athens shales and of limestones of Upper Chazy age, had a parallel but perfectly distinct distribution extending for hundreds of miles. These instances of nearly contemporaneous faunas in lithologically dissimilar beds can not be explained by ascribing them to normal differences in habitat within a continuous sea. The character of the respective faunas is fatal to that explanation, since the more littoral faunas occur on the west side, while the graptolite faunas, which the best authorities regard as essentially pelagic in habitat, are found between them and Appalachia and Taconia, the areas of relatively high land during the Eopaleozoic era.

Not to be misunderstood, it should be said of these examples that neither the Levis nor the Normanskill-Athens zone is believed to be strictly contemporaneous with a limestone formation a few miles to the west. On the contrary, I am of the opinion that these graptolite-bearing shales were deposited at times when the limestone areas were in a state of emergence, and that when the latter were again submerged the Levis and Athens troughs were in part or whole emerged.

The same is true also respecting dissimilar faunas in lithologically similar strata whose contemporaneity may have been suggested by apparent identity of stratigraphic position. I think this is so of the upper Chazy faunas contained in the Valcour limestone in the Champlain Valley and the corresponding Holston limestone in east Tennessee, on the one hand, and the very different faunas found in the upper Stones River in the western part of the Appalachian Valley and in the equivalent Pamelia limestone in central New York. These four formations usually seem to occupy the same stratigraphic interval, being in each case limited below by rocks of middle Chazy age and above by calcareous beds of Black River age. But we know that the Pamelia and the upper Stones River are not of the same age as the upper Chazy formations, since it has been proved by actual superposition at Mercersburg, Pennsylvania, and in Hawkins County, Tennessee, that limestones agreeing closely with the typical upper Chazy are younger than the upper Stones River and older than the Lowville which follows in the same section.

In practice many paleontologists subscribe, latterly perhaps unwittingly or because it had become a habit, to the indefensible belief that the extinction of a species, genus or fauna in a given continental basin usually means its extinction everywhere. In fact, however, this can be true only of species or faunas evolved in and confined to the basin. Moreover, as argued on pages 495-501, such local evolution and development seems to be the exception and not the rule. If the latter supposition is well founded and if the evolutionary stages of faunas as known to us in the fossil state were usually accomplished in oceanic basins permanently inhabited by them, then it is clear that their extinction in any continental basin may be merely as episode in the history of the species or of the life association of which it is a part. At the same time it follows that the partially extinguished species or faunas continued their existence in their permanent oceanic habitats until perchance another opportunity to invade the same or some other continental basin was offered. Granting the foregoing it is reasonably conceivable that under relatively favorable circumstances the process may have been repeated over and over again. Indeed, the already many known recurrences prove that something of the kind took place frequently. Such considerations lead to the following principles, 8 to 11, which are intended chiefly to account for difficulties in correlation arising from faunal recurrences.

(8) Recurrent species and faunas.—*The possibility of recurrence of species and faunas must ever be guarded against.* When properly interpreted, the successive appearances may be used to great advantage in

detailed correlation. The recurrences of a species or fauna may all be limited to a single province but occasionally they extend into areas usually distinct. All fossil species found in two or more successive beds are in fact recurrent, but technically this term is applied only to species whose periodic appearances are separated by considerable intervals in which they are absent. In most cases the several occurrences are distinguishable, and when properly discriminated are of high value in correlation. Good examples are the varieties of *Plectambonites sericeus, Rafinesquina alternata, Leptaena rhomboidalis, Platystrophia lynx, Cyclonema bilix,* and *Calymene callicephalus.* Even when they are not distinguishable the different occurrences may be of excellent stratigraphic service. This is true especially of prolific species whose occurrences are separated by well marked faunas. *Tropidoleptus carinatus* is a notable example. Another that has proved very useful is the *Orthorhyncula linneyi.* The latter is found very abundantly at two Ordovician horizons in Kentucky and middle Tennessee, the first being in the Catheys formation, the second near the top of the Fairview formation. In its second invasion the species extended northward along the Alleghany front to central Pennsylvania. As the species is easily recognized and its second appearance limited to a thin zone it is justly counted among the most reliable and useful of guide fossils.

(9) Time range of fossil species and genera.—*The time range of fossils is ever open to revision, hence no genus or species of fossils is to be accepted as permanently referable to only a single unit of the stratigraphic scale.* A given fossil is diagnostic of a large or smaller unit, as the case may be, only so long as it has not been found in either younger or older positions. This principle is based on the obvious fact that lists of characteristic fossil genera or species of any period, epoch or age are merely expressions of the knowledge at hand concerning the time range of the listed genera and species. Its truth is abundantly attested by comparison of such lists and statements published in the past fifty years or more; and the necessity of seeking endorsement of the organic by the physical criteria, in short, of great caution in deciding on a stratigraphic correlation is emphasized each time a recurrence of species is established or the vertical range of a genus is extended by new discoveries. To blindly accept that a certain genus wherever found is diagnostic of a given epoch or age is to risk impeding progress in exact correlation. At best such practice is justifiable only on the ground of temporary convenience.

(10) Indexical value of species in distinct provinces.—According to views advanced in discussing the paleontological criteria of correlation

(pages 491-501), *the occurrence of a particular genus or species may be relied on as establishing the presence of sediments of the age of which the fossil is thought to be diagnostic only so far as the diastrophic and faunal history of the trough, basin, province or hemisphere has been determined.* The testimony of the fossil, therefore, is unqualifiedly acceptable only within provincial boundaries in which its range has been established. Beyond these boundaries, in some other basin, the same species, or its slightly different ancestor or descendant, may tell a different but no less consistent story. As a theoretic proposition, this principle is generally recognized today, but in practice most paleontologists seem inclined to forget it until the facts have become indisputable. We have, for example, passed the necessity of proving that *Leiorhynchus,* a middle and upper Devonian genus in New York, is found only in much younger rocks in Arkansas and Nevada. But, if I am right, there are many similar and equally notable instances before us, some of them already suggested, others as yet unsuspected. Hence, a species and sometimes even an association of species may be highly diagnostic of a certain bed or formation, and, therefore, of its age, in one basin, and of a different age in another basin or province. This is true more particularly of long-lived species of cosmopolitan habitat which invaded one or another of the continental seas when conditions favored such invasions. *Nidulites favus* is a good example. This species invaded the southern Appalachians, middle Tennessee and central Kentucky areas from the south during middle Stones River time and is diagnostic of this age in those areas. In the Massanutten-Chambersburg basin in the middle Appalachian region a scarcely distinguishable descendant of the same species invaded from the north middle Atlantic and is there diagnostic of the much later Nidulites bed of the Chambersburg formation. The occurrence, mentioned in a preceding paragraph, of very slightly modified descendants of Champlain Valley Chazy species in a later, lower Mohawkian, zone at Lexington and other localities in Virginia, affords an illustration of this principle as applied to an association of species in different basins of the same province. Better known examples are the recurrences of the Hamilton fauna in the Portage and Chemung formations in New York, Pennsylvania, and Maryland, and of the Spergen fauna in the Tennessean and early Pennsylvanian in the Mississippi Valley. The occurrence of nearly identical forms of *Leiorhynchus* in the middle Devonian in New York, in basal Waverlyan in Missouri, and in Tennessean deposits in Arkansas, Nevada and California illustrates the principle as applied to distinct provinces.

(11) Provincial differences in introductory faunal facies.—*A given time may begin in one area with a fauna differing greatly from that which introduces the same period elsewhere.* In one case the general facies is obviously like that of faunas preceding it in the same area; in the other it is more like the locally succeeding faunas. In the former it is usually found that the same basin contained a large fauna during the age immediately preceding and that this older fauna simply continued into the next, or was replaced by a derivative of the preceding fauna evolved in the same oceanic basin during an intervening stage of sea withdrawal. In the latter case the new sea submerged, or the new fauna entered, areas that for a long time previously had been either land or were merely inhospitable to types of marine life characterizing the invading new fauna; or the new fauna invaded from a different oceanic basin than the one which supplied the preceding local facies. Examples of the former condition are the Ohio-Indiana Richmond and the Bradfordian of Pennsylvania and New York, in both of which the new faunas found the ground already occupied by large and as yet but little changed descendants of preceding vigorous and in a way indigenous faunas. The latter condition is exemplified by the western Richmond and better by the Medina Richmond of New York and the Appalachian area generally; also usually by the middle western Kinderhook faunas. In each of these instances the fauna is markedly different from the one next beneath it.

The new facies in these cases invaded areas that for a long time previously had not been submerged. As they were not obliged to contest the ground with surviving older faunas that elsewhere (as in the vicinity of Cincinnati) still had access to certain continental basins, the local faunal break under these circumstances may be very sharp. It is especially so when, as in the case of the Richmond fauna following the Trinucleus fauna in the Viola limestone in central Oklahoma,[65] the locally superposed faunas invaded from different oceanic provinces. If, however, they invaded from the same oceanic basin, even if a long period intervened, the value of the hiatus may be obscured by inherited similarities. This condition is illustrated by the Black River and Richmond phases of the slowly modifying Arctic fauna, which so often succeed each other without intervention of Trenton and Cincinnati faunas.

This principle may be expressed somewhat differently as follows: Though the general facies of a fauna may be greatly like that of a certain period, it may nevertheless belong to the next succeeding period. The true age of such faunas is usually indicated by one or more types else-

[65] Tishomingo Folio, Geol. Atlas U. S., No. 98, 1903.

where characteristic of the later period. Examples: The Richmond and the Helderbergian faunas, the Glen Park Kinderhook fauna, and the Bradfordian Kinderhook fauna. The Richmondian faunas are decidedly Ordovician in general aspect, and the Helderbergian series contains a large percentage of species reminding more of middle and late Silurian than of Devonian forms. Yet, relying on diastrophic criteria and the introduction of new organic types, the former are shown to be early Silurian in age and the latter early Devonian. Similarly the Glen Park fauna recently described by Weller, though reminding strongly of the Hamilton, is of Kinderhook age. The Bradfordian also is of Kinderhook age despite the greatly predominating Chemung element in its fauna. On precisely the same grounds, namely, diastrophism and introduction of new types, I refer the Sainte Genevieve to the base of the Chesterian and the Warsaw to the base of the Meramecian.

(12) Value of pelagic species in correlation.—*Pelagic species and faunas, notably the graptolites and the later thin-shelled coiled cephalopods, are of great value in intercontinental correlation.* Their use in correlating the deposits of the more shallow and limited Paleozoic continental seas, however, is reduced to the infrequent occasions when these seas and troughs became thoroughfares for oceanic currents. As a rule such occurrences are marked by black shale deposits. The Levis and Normanskill graptolites, found in Sweden, Great Britain, Newfoundland, Quebec, New York, Arkansas, and Australia, are excellent examples.

(13) Relation of marine currents to faunal distribution.—*Absence of certain classes of invertebrates in the whole or parts of continental seas is more often due to discontinuance of currents than to increasingly unfavorable environment.* Such progressive changes in the composition of fossil faunas, therefore, are not indicative of corresponding differences in age; neither do they indicate provincial differences. They mean only that the marine currents to which the organisms in question owe their presence in the basin either lost their efficiency or that they were diverted to offshore areas that were more or less unfavorable to the development of shallow-water life.

Striking differences are often found in comparing lists of fossils gathered at distant outcrops that are referred on perfectly competent evidence to the same age and same continental sea. These differences are especially noteworthy in the case of widely recognized formations, which maintain essentially similar lithologic characters and in which, therefore, the observed changes are not readily explained on the ground of unfavorable environment. On close comparison of such faunal lists, it is usually

found that the changes do not affect the fauna as a whole, but that they are almost entirely confined to classes comprising forms whose migration from place to place is more or less completely dependent on marine currents.

Among Paleozoic faunas nearly all of the species so limited belong to the lithisdid sponges, the reef forming corals and the bryozoa, most of which begin with a free-swimming larval stage but later on assume a sessile habit of growth. In that they depend on marine currents for the extension of their ranges, these organisms resemble the planktonic or pelagic species, but in their mature conditions they are very different. Thus, while the truly pelagic forms breed and pass their existence near the surface of the water and are quite indifferent to its depth and to the character of the bottom beneath them—features insuring extraordinary extension of range—the corals and other things immediately under consideration require limited depths of water and certain bottom conditions before their larvæ can secure a suitable foothold and develop mature characteristics. Although the geographical range of such species in continental seas is commonly less than that of the mollusks, crustacea, and brachiopods, it is, on the contrary, greater where, as between different continents, it is necessary to cross relatively wide and deep seaways which would more effectually bar the distribution of the other classes.

The diminution and perhaps final extinction of sponges, corals, and bryozoa away from the inlet, as northeastward from the Mississippi embayment in the case of the upper Stones River, the Lowville, and the Onondaga, especially in view of the fact that a similar diminution is more or less clearly manifested by all the faunas invading from the Gulf of Mexico, can not be wholly attributed to increasing unfavorableness of environment. Unfavorable conditions of bottom doubtless are responsible for much of the irregularity of distribution, but not for its final extent. This depends on whether there is a current capable of carrying the free larvæ past the unfavored to more propitious areas.

It is thus that the absence in the Pamelia in New York of the numerous sponges, corals, and bryozoa found in the corresponding parts of the Stones River group in Tennessee is explained. Also the slower elimination of these classes in the Lowville fauna northward from middle Tennessee.

Regarding these current-transported mero-planktonic constituents of faunas, it is to be further noted that within the same continental sea their occurrence in deposits perhaps hundreds or even thousands of miles apart is a fact deserving the highest consideration. It is therefore with implicit

confidence that the beds in New York, Kentucky, Tennessee, and Arkansas, containing *Tetradium cellulosum* and certain equally characteristic bryozoa, are referred to the same age and formation, namely, the upper Lowville. Again, that beds of earliest Trenton and late Black River ages in Iowa and Minnesota are exactly correlated with deposits in areas far to the north and south on the ground of identity of their respective bryozoan faunas, and scarcely less definitely with formations in the Baltic region of Russia, because the latter contain over 60 species of bryozoa originally described from Minnesota. Finally, this confidence is no less in the even more extraordinary case of a Richmond coral zone, which is recognized locally in America from Missouri to western Texas and New Mexico and in a northerly direction to Alaska and Baffinland and in almost identical development in the upper Lyckholm of Russia.

"Stages of evolution" is used by some authorities, notably Hyatt, but as a rule this class of criteria can not lead to very exact results, and at that is usually too intricate to be generally applied. However, it is of excellent service where the successive mutations marking the life history of long enduring, broadly conceived species is concerned. The successive stages of certain brachiopods, notably *Plectambonites sericeus, Dalmanella testudinaria,* and *Leptæna rhomboidalis,* which are usually very abundant and widely distributed geographically, have been used with marked success.

Stages indicating decadence of species or genera also have been used, but as this condition may be due to purely local causes the interpretation is liable to grave error.

While the evidence of the fossils may in most cases suffice in establishing a correlation, it is yet recommended that the organic evidence be checked and supplemented by all physical evidence that may have a bearing on the problem.

CORRELATION BY LITHOLOGIC SIMILARITY

Value of this method.—Obviously, correlation by lithologic similarity is inferior in geographic extent of application, and perhaps also in general reliability, to the other three methods implying more or less of deductive reasoning, namely, by fossils, by criteria of active diastrophism, and by evidence indicating slow, general sea transgression. Clearly, also, the present method is closely connected with the other modes and more often in need of their corroboration. Still, within reasonable limits, geographic and otherwise, and when constantly checked by fossil and diastrophic evidence, lithologic criteria are of great value in exact correlations. They are especially serviceable and reliable when for various reasons it has be-

come evident that the deposits were laid down under similar physical conditions, as, for instance, in each of the structural troughs of the Appalachian region, and around the borders of inland areas of uplift. Following the treatment adopted in discussing the principles of correlation by organic remains, those of lithologic similarity would be as follows:

(1) *Importance of geographic persistence of lithologic characters in establishing contemporaneity of deposition.*—A stratigraphic unit of the rank of a formation or of a member, whether composed of dolomite, pure limestone, calcareous sandstone, or shale, or of alternating strata of such petrologic units, may be considered as an essentially contemporaneous deposit so long as it maintains its lithologic characteristics and does not lose recognizable beds from its base or top. When such loss occurs, as in overlaps or because of erosion subsequent to deposition, the remaining parts may yet be accurately correlated with corresponding beds in more complete sections. Such exact correlations may be carried by easy stages over hundreds of miles.

The upper Stones River, for instance, is an unusually good example. Indeed the lithologic characteristics in this case are more readily serviceable and, as shown by experience, no less reliable than the fossils in tracing the stratigraphic unit from Alabama to New York and Canada, where it is now known as the Pamelia limestone. Through all this distance the greater part of this formation consists of dense-textured dove-colored pure limestone, often rather heavy bedded in its middle to upper portion and generally thin bedded below and at the top, while the middle fifth or so seldom fails to contain more or less highly magnesian ledges. On the western side of the Alleghany basin in central Kentucky and west middle Tennessee similar magnesian limestone forms the top division (Carter limestone and Oregon dolomite) of the Stones River group. In the absence of positive faunal evidence, we are forced to rely almost solely on lithologic similarity in correlating the Carter limestone with the magnesian part of the upper Stones Rives in the Appalachian Valley.

The Lowville overlies the upper Chazy in the Champlain Valley and in the vicinity of Mercersburg, Pennsylvania, but in the western part of the Appalachian Valley and in New York, Kentucky, and middle Tennessee it rests on the upper Stones River, which it resembles petrologically. However, the Lowville is constantly a purer limestone and, though closely simulating the Stones River in texture and color, the two can nearly always be distinguished without the aid of fossils. Fortunately, diagnostic fossils are rarely wanting in the Lowville, so that the lithologic test need be but loosely applied, the identification of the formation

being chiefly on faunal and stratigraphic evidence. Still, in the matter of constancy of lithologic characters and geographic extent, the Lowville is perhaps the most notable of all Paleozoic limestone formations.

Scarcely less excellent cases of persistence of lithologic character occur among the shale and calcareous sandstone formations. Good examples are the Utica black shale, distributed from Cincinnati to New York, the greenish or bluish Eden shale horizon, which is unmistakably recognizable in outcrops and in deep wells from Kentucky to central New York and in the Appalachian shale formations from Pennsylvania to Tennessee, and the Cincinnatian calcareous "Bays" sandstone, which maintains its petrological characters and stratigraphic position in the middle and western synclines of the Appalachian Valley from Pennsylvania to Tennessee. The essential contemporaneity of geographically widely separated deposits in these and many other instances that might be mentioned of lithologic constancy among Paleozoic formations is clearly established by paleontologic and diastrophic evidence and by stratigraphic position. Lithologic similarity, therefore, when checked by these other criteria, is an important and usually reliable means of correlation.

(2) *Sandstones often of low value in correlation.*—Relatively pure quartz sandstone formations are not generally of value in determining contemporaneity of deposition. Of the different kinds of sedimentary rocks, sandstones, viewed as a class, are the least reliable for such purposes. This is particularly true of sandstone deposits at the base of an overlapping formation. Any sandstone immediately following a much older formation, or separating two formations proved by fossil or other evidence to be widely different in age, is to be regarded as probably varying in age from place to place according to the progress of a transgressing sea. Notable examples are (1) the Lamotte sandstone and the Reagan sandstone, respectively, at the base of the overlapping upper Cambrian in Missouri and Oklahoma; (2) the sandstone of the "Saint Peter" group, which overlaps northwardly, so that its base is older in Arkansas than in Minnesota; (3) the sandstone of the "Oriskany" group, which in crossing the State of New York from the east to the west rises stratigraphically; (4) the sandstone at the base of the overlapping Kinderhook series in northern Arkansas and southern Missouri, and (5) the Trinity sandstone, which registers the slow advance of the Cretaceous sea from Texas into the States north of it.

For obvious reasons such overlapping sandstones are to be counted with diastrophic criteria rather than the purely lithologic. As tending the other way I would mention certain sandstone formations, like the

Weisner quartzite in Georgia and Alabama, which probably includes beds that are strictly contemporaneous with similar beds in the Chilhowee series in Tennessee, and in the lower Cambrian quartzites in Virginia, Pennsylvania, and Vermont. But their exact determination seems as yet impossible. In fact, exact correlations of individual beds of lower Cambrian deposits in the Appalachian Valley seem possible only to a very limited extent. Combining all the methods we can go but little further than to say that the quartzites containing *Olenellus* in the Appalachian region are of lower Cambrian age.

But there are some sandstones that are of much greater practical value in correlation. Such are the well defined beds that occur at intervals in shale formations, as the one (Kiefer sandstone) at the base of the Cayugan series in Maryland and Pennsylvania, and the red Bloomsburg sandstone, which is found higher up in the series and separates the lower (McKenzie) formation from the shaly middle (Wills Creek) formation of the Cayugan series; also the conglomerate sandstone, which marks the lower limit of the typical Chemung fauna in the Jennings formation. In going both eastward and westward from the middle part of the Appalachian Valley these sandstones usually become thinner and may finally be lost entirely; but so far as they are recognizable they afford the most ready, and I believe also the most reliable, of the several means employed in correlating the local subdivisions of the late Silurian and late Devonian deposits. Similar, though perhaps less accurate, results are attained by using the sandstone beds in the Ozarkian system in Missouri. The value of these as datum planes was recognized long ago by Swallow and Shumard, and though less regularly distributed than they thought and therefore often misidentified, the present revised classification of the Cambrian and Ozarkian rocks in Missouri would, I fear, have been impossible without the aid of these sandstones.

(3) *Similarity in lithologic character and stratigraphic position does not establish contemporaneity.*—Correlation of similar lithologic units based otherwise only on apparent likeness of stratigraphic position is always unsafe and never conclusive. The practice of this simple method seemed safe enough under the old idea of universal seas, but with the proof of frequent and diverse sea oscillation growing stronger every day it can no longer be relied on. Geological literature is full of errors due to such insufficiently grounded correlations, and the chances for error are not much greater when the correlated units are dissimilar lithically. Contemporaneity is to be assumed in cases of lithologic similarity of beds not continuously traceable only when the organic criteria prove that

they have been deposited within the same continental basin or in more exceptional instances when they fall within the broader limits of a faunal province. Beyond such limits exact contemporaneity can not be established absolutely, however similar the beds may be in petrological characters. Approximate contemporaneity in such cases is assured only when such beds are bounded above and beneath by more widely transgressing stratigraphic units or faunal zones of not very different ages. In the absence of such determining zones essential contemporaneity may sometimes be established by diastrophic criteria.

Using a large unit the principle is illustrated by the lithologically varying representatives of the Waverlyan system in the three or more subdivisions of the Ohioan province recognizable in this period. Thus, the equivalents of the sandy and shaly formations of Waverlyan age in the Appalachian Valley north of Tennessee and east of the Cincinnati axis can not be determined by lithological criteria in the cherty Tullahoma and Fort Payne limestones of Tennessee and Alabama, nor in the limestone and calcareous shale deposits of this period in the Mississippi Valley above Saint Louis. Within each of these subprovinces the lithic features of the formations remain fairly constant, so that correlations by similarity of such characters is practicable over areas of considerable extent. But beyond these correlations are possible only by means of diastrophic criteria indicated by changes in sediments and faunas. Using smaller units we have good illustrations (1) in the Kimmswick limestone, which has been erroneously correlated with the Galena dolomite because both are preceded by limestones of Lowville age ("lower Trenton") and succeeded by Maquoketa shale; (2) in the Lowville limestone in east central Tennessee, which was classified as Carter limestone because both are underlain by the Lebanon limestone and overlain by the Hermitage shale; (3) in the Izard limestone of Arkansas, erroneously correlated by Ulrich with the Viola limestone of Oklahoma, and (4) in the Bertie waterlime, which was referred to the Rondout until it was proved an older bed.

(4) *Correlation of dissimilar lithologic units.*—Difference in lithologic characters of beds that are not continuously exposed, but occupy similar positions in the stratigraphic column, is always suggestive of difference in age, providing the faunas are not the same. If both the fauna and the kind of rock remain unchanged in a given broad region, and if both factors are appreciably and uniformly different in another wide area, one of two conclusions is to be drawn: either the two kinds of rock are of the same age and the differences are due solely to provincial distinc-

tions or they are different in both respects. A satisfactory solution between these two interpretations is usually a very difficult matter. Stratigraphic geology is full of such problems, many of them scarcely suspected and a large proportion quite unsolved.

An unusually good and difficult illustration of this principle is presented by the taxonomic relations of the dolomitic Niagaran limestones of North America north of Saint Louis and New York to the non-dolomitic deposits of the same series in Kentucky, Tennessee, and northern Arkansas. The latter extend up the Mississippi valley by outcrop to Perry County, Missouri, where they pinch out by overlap. They probably extend farther northward in Illinois under cover of later rocks. The dolomites extend southward from Wisconsin and Iowa, growing thinner but not changing in character as they proceed, to Grafton, Illinois, and Lincoln County, Missouri, beyond which points this Silurian type of rock is seen no more. Except locally neither crosses an irregular intermediate line. In other words, it is not a case of lateral transition from the one kind of rock to the other, but of an actual land barrier separating the northern waters from the southern. Now, did these two seas occupy their respective continental basins at the same time, or did each pulsate back and forth, so that when the northern sea retreated the southern waters advanced? We get some light on the question from the overlap of the two types in western New York, but the problem is still an unsettled one. As a matter of opinion, based chiefly on philosophical considerations discussed on pages 422 to 425 and 558 to 561, I favor the latter view.

A very similar problem, now largely solved, is the age relation of the Galena dolomite of the upper Mississippi Valley and the north and west generally to the Mohawkian formations in the south and east. Prior to 1895 the Galena was usually regarded as late Trenton in age, and on three occasions, the last in 1879,[66] it was correlated with the Utica shale of New York. Until very recently[67] the Kimmswick limestone, which is known by frequent outcrops in eastern Missouri south of Pike County and in northern Arkansas and south central Tennessee, was referred to as the southern equivalent of the Galena. By discovery of lower to middle Galena, typical in fauna and rock, resting on upper Kimmswick limestone in Pike and Lincoln counties, Missouri, the error of this supposition is now established. We know further that the lower Galena (Pros-

[66] C. D. Walcott: The Utica slate and related formations. Trans. Albany Inst., vol. x.

[67] T. E. Savage: American Journal Science, vol. xxv, 1908, pp. 431-443, still refers to the Kimmswick as "Galena Trenton," but in vol. xxviii, p. 512, of the same journal, he modifies this view slightly by correlating the formation with the Fusispira bed of the Minnesota section.

ser limestone) fauna underlies the base of the typical Trenton section in New York, and that it precedes the corresponding boundary also in Kentucky. Moreover, a slight unconformity at the top of the bed containing the Prosser limestone fauna in New York and Kentucky suggests a hiatus that probably represents the middle and possibly also the upper Galena. At least two-thirds of the Galena, plus the Kimmswick, therefore, belong between the base of the *Prasopora simulatrix* bed, which is usually counted the basal member of the typical Trenton, and the top of the Black River group in Oneida County, New York. At present, then, only the upper third of the Galena remains to be accounted for. Evidence in hand suggests that a part (the Dubuque limestone) of this upper division of the Galena is probably post-Trenton in age, but until we know definitely what to do with it the post-Prosser part of the Galena may be placed opposite the middle Trenton. It is to be noted, however, that correlation results like these, while led up to by lithologic criteria, are finally established mainly on faunal and diastrophic grounds.

(5) *Sequence of lithologic units.*—Similarity in succession of types of sedimentary rock, as of faunules, is of high value in correlating near-by exposures and is of considerable use in comparing even widely separated sections. Rarely this method may serve when the evidence of the fossils is not by itself conclusive. So far as possible, however, the successive steps of the correlation should be checked by the organic criteria; otherwise great error may result. The Ordovician sections in central New York and Kentucky afford a good illustration of the legitimate application of the principle. Starting with the upper Stones River limestone, which is practically the same in the two areas, the succeeding formation is the Lowville limestone, which likewise agrees. Between the Lowville and the *Prasopora simulatrix* zone (Wilmore limestone in Kentucky), a shaly limestone easily recognized in both sections, come several thin, late Black River and early Trenton beds that vary rapidly in thickness and may be locally absent. Exact correlation of the succeeding Trenton beds is more difficult, even with the help of abundant fossils, and the lithologic criteria are quite as useful here as any of the other means. In each of the two areas this part of the Trenton is marked by sea oscillation and consequent local peculiarities in sedimentation and faunal development. The Trenton is followed by the widely overlapping black and gray Utica shale. Only the upper part of this lithologically and faunally characteristic zone reaches northern Kentucky, but it thickens and is well known from deep-well records in Ohio. Lithologic and faunal similarity continues in the two sections to the arenaceous top of the Lor-

raine in New York and to the corresponding top of the Mount Hope bed of the Maysville group at Cincinnati. Above this horizon correlation of Ordovician and basal Silurian deposits by means of lithologic similarity is no longer possible.

Correlation by similarity in succession of rock types is an even more feasible proposition between central Kentucky and middle Tennessee than between the former and New York. In this case it is practical not only for the whole of the Ordovician, but also for most of the Silurian. Certain formations are absent in one and present in the other, but these lapses are easily detected by the paleontologist. The only really perplexing difference is in the Richmond deposits, and this proves to be due to provincial distinctions. The close similarity in lithologic units existing in Kentucky and Tennessee is shown by the following list of sixteen Ordovician and Silurian formations and members clearly recognizable in the two areas: Middle Stones River, Lebanon limestone, Carter limestone, Lowville limestone, Hermitage formation, Bigby limestone, Flanigan chert, Perryville limestone, Catheys formation, Fairview limestone (included in the Leiper formation in Tennessee), Arnheim shale, Brassfield limestone, Osgood limestone, Laurel limestone, Waldron shale, and Louisville limestone. One Ordovician formation, the Kimmswick, two Richmondian, and two or three Niagaran beds beneath the Louisville limestone have been found in Tennessee, but are so far unknown in Kentucky, while three of the Ordovician zones in Kentucky—the Curdsville, Eden, and McMillan—and the Saluda-Whitewater beds of the Richmondian, do not outcrop in Tennessee.

(6) *Apparent lithologic units often include stratigraphic hiatuses.*—Lithologic units, using the term in the stratigraphic sense, may or may not signify continuous deposition. Very important stratigraphic boundaries, perhaps marking great hiatuses, are often included in an apparent lithologic unit. Indeed, the contact plane may be so tightly cemented that the rock above and beneath it forms a single layer. The latter is a common occurrence when a fine-grained limestone, like the Lowville or the Stones River, is on either side of the line. In the Mohawk Valley of New York the top surface of the Lowville is often smoothly planed, either parallel with or slightly across the bedding planes, and riddled with vertical worm bores an inch or two in length. Generally not a vestige of detrital matter separates this surface from the overlying darker limestone (of some later Black River or early Trenton age), which fills the burrows and forms so close a joint that hand specimens showing the contact are easily procured.

Somewhat different cases are certain sandstone and shale deposits which at one point may seem to constitute a single, indivisible lithologic unit, but when traced along the outcrop are seen to divide at some plane between the top and bottom of the bed. Four instances come to mind, two in which the dividing bed is of sandstone and two of shale. The first is the rather well known case of the Glauconite sandstone of the Baltic region, which wedges apart in Sweden so as to inclose the Ceratopyge limestone between an upper and a lower division of a bed that elsewhere has the appearance of an indivisible unit. The second case is more remarkable because the included hiatus is much greater. It was observed at several localities in northern Arkansas and concerns a white quartzose sandstone which on several occasions had been mapped as a unit, but of which, it was found on closer investigation, the lower part is of Saint Peter or earliest Ordovician age, while the upper part is early Waverlyan, being either the Sylamore sandstone member of the Chattanooga formation or a sandstone at the base of some stage of the succeeding Kinderhook overlap. Away from the points where the sandstones unite in a single lithologic "unit" the upper and lower parts diverge until they are separated by from 500 to 600 feet of Ordovician and Silurian limestone (see figure 17 D, page 450). Without knowledge of these facts one would be likely to refer the combined sandstones to either the Saint Peter or the Sylamore. These two beds are exceedingly similar, the latter, in fact, having been derived by erosion from exposed areas of the former.

Splitting of shale formations seems a less common phenomenon. Two good cases, however, come to mind. One was only recently described by Morse and Foerste.[68] This is the black shale in central Kentucky commonly known in literature as the Ohio shale, or, more properly, as the Chattanooga shale. Traced northwardly into Ohio, this bed of shale splits into two parts, the upper being known as the Sunbury shale, the lower as the Cleveland shale. These diverge more and more until in northern Ohio both are subordinated in volume to the intercalated Berea grit and the Bedford shale. The second case is that of the Woodford and Caney shales in Oklahoma. Locally, these two black shale formations succeed each other, and they are distinguished chiefly by the fact that the lower (Woodford) contains a considerable amount of thin, platy chert never seen in the upper. But this chert is sometimes scant or wanting in the upper 100 feet or so of the Woodford, in which case the contact between the two formations is difficult to locate. At other localities in the region of the Arbuckle uplift this contact diverges until it includes 300 to

[68] Journal Geology, vol. xvii, 1909, p. 164-177.

440 feet of shaly and massive Sycamore limestone, and this included mass is bounded both above and below by an unconformity. Finally the hiatus at the top of the Sycamore is regarded as representing the time during which some 10,000 to 15,000 feet of Stanley shale and Jackfork sandstone were deposited in the near-by Ouachita synclines. This opinion is based on three facts: (1) that the Sycamore contains early Tennessean fossils; (2) that the Stanley shale contains younger, probably early Pottsville plants, and (3) that the typical Caney shale overlies the Jackfork sandstone.

(7) *Passage beds with or without interrupted sedimentation.*—Transition from one kind of sedimentary rock to another—as from a sandstone to a shale or from either to a limestone, or from a limestone to a shale—even when the change is abrupt, often occurred without discontinuity of deposition. On the contrary, even a "gradual passage" does not preclude the possibility of a long interruption of the process of sedimentation at such places and times.

Interruption in the latter cases is least likely when the transition is from sandstone to shale deposition. Transition without break occurred also, though rather infrequently when the passage is from shale, or even from sandstone, to limestone. Theoretically such transition signifies merely a lowering of the land with respect to sealevel, as when erosion of the land reduces its gradient, so that the coarser clastic deposits give way to finer-grained sediments, or when the sea rises higher and higher with respect to the land.

Occurrences of transition from sandstone to shale and from shale to limestone without known interruption of deposition are too common to require citation of instances. Uninterrupted transition from sandstone to limestone, not counting passages from such thin, sandy and conglomeratic, initial deposits of overlapping limestone formations, like the Devonian limestone on the north flank of the Ozark uplift and certain Kinderhookian limestones on the south flank of the same, in Missouri, are less common. The passage from the Potsdam sandstone to the Little Falls dolomite in New York, from Oriskany sandstone to Oriskany limestone in Maryland, east of Hancock, and from the Jordan sandstone to the Oneota dolomite in the upper Mississippi Valley, are fairly good examples. An excellent and indubitable instance is seen in the transition from the Saint Peter sandstone to the Joachim magnesian limestone in eastern Missouri and northern Arkansas. On casual inspection the passage from the sandstone to the limestone, in especially the last of these cases, may seem abrupt, but on close examination it is usually found that the lower part of the limestone is filled with downwardly multiplying, floating, and probably wind-blown grains of quartz.

Examples of transition from a limestone to a sandstone formation without interruption of deposition are rare. The only good one that has come under my observation is that of the Everett limestone and the Saint Peter sandstone in northern Arkansas. Typically developed, the Everett is a fine-grained, nearly pure limestone, locally exceeding 100 feet in thickness. Usually the upper few feet contain a considerable amount of quartz in the shape of floating grains, which become more abundant upward and are rounded like those of the overlying Saint Peter. At other places, as directly south of Yellville, a large part of the limestone may be filled with such grains. Where this is so the calcareous part of the rock is often removed by solution, leaving an incoherent mass of quartz sand. The Saint Peter sandstone itself doubtless was originally cemented with lime, which has since been dissolved and carried away by circulating ground waters. Under Cincinnati, where the corresponding bed gives rise to an artesian flow of sulpho-saline water, it retains much of its original limy binding.

From these and other ascertained facts it is inferred that deposition continued practically uninterruptedly in parts of northern Arkansas from the beginning of the Everton limestone to the close of the Joachim. The latter, apparently, is the calcareous offshore phase following the northward advance of the Saint Peter beach. As for the Everton stage of the process, it differed chiefly in that the available supply of quartz sand was then much smaller than it became in the Saint Peter stage.

Trenton deposition in the area to the north and east of Little Falls, New York, offers an excellent example of gradual passage from limestone to shale deposits. Here only the early part of the Trenton age is represented by limestone. This grows more and more argillaceous upward until it passes, so far as observed without interruption of sedimentation, into black shale, which resembles the Utica very closely, but is still of lower to middle Trenton age.

Though transitions from limestone to shale occurred often without break in deposition, this condition is nevertheless one that always deserves close scrutiny. This is true especially when two limestone formations are separated by a thin bed of shale or of irregularly stratified clayey matter. When the concerned beds are fossiliferous the organic remains will usually indicate at once whether the contact between the lower limestone and the shale marks a break in deposition. When they do the limestone floor is always uneven and generally exhibits other clear evidence of preceding emergence and erosion.

In the case of moderately thick beds of shale following limestone the

widely transgressing Chattanooga shale in the Mississippi Valley offers many notable examples of a preceding stratigraphic hiatus. Other examples are seen in the contact of the Fayettesville shale and various underlying limestones in northwestern Arkansas and northeastern Oklahoma. Others, again, were noted in the vicinity of Saint Joe, Arkansas, where the upper shale of the Morrow group sometimes rests on eroded Pitkin limestone, and in Calhoun County, Illinois, where an early Waverlyan shale was laid on the weathered surface of a late Devonian limestone. In all of these instances (more fully described on page 465) the subaerial weathering of the limestone bed before deposition of the shale began is indubitably proved by the discovery of partially weathered-out fossils projecting from the surface of the limestone and others completely freed that were preserved in small hollows. Though the contact is unconformable in these cases, the fact is but rarely indicated by distinct divergence of bedding planes.

Cases of interrupted sedimentation marked by thin seams of clayey matter between two limestone formations, though also very common, are often obscurely indicated and in the absence of fossils much more difficult to establish. The underlying surface is usually undulating and the succeeding clay seam, which represents reworked residual material and whose maximum thickness may not exceed an inch or two, fills the small hollows and often pinches out entirely. Such a contact occurs between the Kimmswick and the Fernvale limestone south of Saint Louis. Another example is found in the exposures of Girardeau limestone in contact with an early Niagaran limestone in a railroad cut two miles above Cape Girardeau, Missouri, and near Sainte Genevieve, in the same State, where the Sainte Genevieve limestone rests on the Saint Louis limestone. In each of these cases the break might not be suspected in fresh cuts, but is clear enough in weathered exposures.

Other good examples were noted in the Helderbergian series in Maryland and West Virginia. Of these the Coeymans-New Scotland contact is, for several reasons, especially convincing of interrupted sedimentation. Comparison of numerous sections has shown that the beds in contact vary from place to place, and satisfactory evidence of old surface material has been seen in the intervening clay seam at a number of localities.

Many instances of apparently gradual change in character of sediment, when in fact the transition beds either include or follow a demonstrable hiatus, might be cited. Such cases are explained on the justifiable assumption that the first overlapping deposits of an advancing sea would

naturally be made up in greater or smaller part of material derived from the underlying formation. Under average conditions this imitation should be greatest when the subsiding floor is a sandstone, somewhat less when a shale and least when a limestone. In the last the new deposit is usually a calcareous shale or an argillaceous limestone, with the two frequently occurring in alternating layers.

Of sandstones following older sandstones after a long interval of non-deposition and then grading into some other kind of rock I would cite (1) the case of the Waverlyan Sylamore sandstone in northern Arkansas, where it sometimes rests on the Saint Peter and passes upward into black Chattanooga shale, and (2) the apparent gradation from an Ozarkian sandstone into sandstone and shale of Pottsville age, observed in Missouri near Bolivar and at several localities in the southern part of Saint Clair County. Despite the great time value of the hiatus in these cases it is very difficult to draw the boundary between the old and the younger deposits.

Similarly obscured interruptions of deposition, with shale under and above the break, are illustrated by (1) the transition from the black fissile Chattanooga shale to the bluish calcareous Ridgetop shale (early Kinderhookian), found locally beneath the Fort Payne limestone in middle Tennessee, and (2) the passage from the black Woodford shale to the similar Caney shale when the intervening Sycamore limestone is absent, or to gray sandy shale where the Sycamore is represented in part by shale, or again from these gray shales to the black shales of the Caney, all of which conditions were observed near Wapanucka and in the vicinity of Bengal, in Oklahoma. In the first example the hiatus is small and locally seems to be closed entirely. In the second, as explained on page 527, the break, though varying in value, is yet of great importance in each of the three phases mentioned.

The hiatus in apparently gradual but really broken passages from a limestone to a shale formation is always difficult to establish except between highly fossiliferous beds. As a rule, too, the hiatus is not of great value. The transition from the Trenton to the Utica is often gradual, but in most cases it is possible to show that some interruption of sedimentation occurred between them. The transition from the Chambersburg limestone to the Martinsburg shale in the Cumberland Valley in southern Pennsylvania, Maryland and northern Virginia, likewise commonly seems gradual. However, as described on pages 323 to 328, the two formations are always separated by an hiatus partly measured in places by known absence of hundreds of feet of limestone.

CORRELATION BY DIASTROPHIC MOVEMENTS

General discussion of principles.—Diastrophism, the initial cause of physical and organic change, is urged by Chamberlin as the ultimate basis of correlation. The essential features of his conclusion are ably presented by this writer in a recent short paper on the subject[69], and also by Willis[70] who emphasizes certain aspects not definitely stated by the former. Assuming the principle of periodicity of great deformations, both conclude that the baseleveling of the land in the relatively quiescent stages between the periods of active diastrophism "means contemporaneous filling of the sea basins by transferred matter," and that the resulting advance of the sea "is essentially contemporaneous the world over" (Chamberlin op. cit., page 690). Willis thinks "the eras of inactivity, the baselevel eras for the whole world," were very long, and because of "their very great duration, from which their essential contemporaneity results," they are unfitted "for any except the broadest outline of classification." Further on he adds that these baselevel eras "afforded the best conditions for correlation by the other criteria." Regarding periods of active diastrophic movement he says, they "have been shorter than the eras of baseleveling, and consequently define time divisions, which are more nearly commensurate with those of current geologic standards. They are, however, still long, and their value is in broad fundamental classification." That Willis believes only very crude, generalized, correlations are possible by means of continental and orogenic movements is evident from the following statement: "Disturbance and quiet, erosion and continuous deposition, unconformity and conformity, have developed simultaneously in immediately adjacent districts many times" (Willis, op. cit., pages 255, 256). Finally, according to this author, only the occasional world-wide ebbs, resulting from subsidences beneath the oceans, would seem to constitute anything like an exact measure of contemporaneity.

Chamberlin and Willis have presented the theoretic aspects of the principles of diastrophic correlation in sufficient detail, but, so far as I know, no practical application of the proposition, except in the broadest and most generalized terms, has been published. Indeed, such application is no easy matter, the problems being exceedingly complex and quite insolvable except with the aid of the most refined paleontological methods. Chamberlin probably recognizes this fact when he says "if we add the biological element the case is immeasurably strengthened;"

[69] T. C. Chamberlin: Diastrophism the ultimate basis of correlation. Journal Geology, vol. 17, 1909, pp. 685-693.

[70] Bailey Willis: Principles of paleogeography. Science, Feb. 18, 1910.

but he seems to underrate and misapprehend the difficulties when he adds "for correlation by cosmopolitan faunas, the very best of faunas for the purpose, is added to the physical correlation." Aside from the pelagic faunas, and using the term in not too broad a sense, is there, or has there ever been, a truly cosmopolitan fauna? For reasons given on page 366, the forms comprising the so-called cosmopolitan faunas, instead of being contemporaneous, are more probably either later or earlier stages of slowly modifying species, and, consequently, of little value in exact correlation.

Except those afforded by pelagic and free swimming species, there are no highways, no "short-cuts" to world-wide correlations. On the contrary, stratigraphic correlation, whether we use physical or biological criteria, or both, is a slow, laborious process, each method requiring constant corroboration by the other methods, with no certainty of results until we have closed the circle and proved the process. As we proceed from a given locality, the organic and the lithologic evidence first depended upon grows ever weaker until one or both pass out entirely. Fortunately, the continuance of diastrophic lines frequently enables us to mend the broken thread; and herein diastrophism proves itself not only the theoretic basis of correlation, but its criteria show themselves to be eminently practical.

Though fully endorsing Chamberlin and Willis's claims for diastrophism as the ultimate basis of correlation, and though affirming the exceeding value of diastrophic criteria when abundantly checked and corroborated by paleontological and lithological evidence, I must yet frankly admit that by themselves these criteria are utterly valueless in correlating widely disconnected outcrops. Diastrophic criteria are so variable in local expression, and their successive manifestations so similar in general aspect and range of variability that positive and unerring discrimination seems impossible. We may determine the position of certain stratigraphic boundaries, as between bodies of limestone and shale or sandstone, or we may note and trace some persistent zone of overlap and possible conglomerate, but what these lines mean in the time scale may, as a rule, be determined only by fossils. Moreover, it has frequently happened that the most important boundaries were entirely overlooked when the geologist took into account solely the obvious changes in character of deposits. That the supposed lithological unit included one or more great discontinuities of sedimentation, or that the formation spanned two or more systems and thus made no provision for the discrimination of important, elsewhere perhaps more clearly defined, geological events, was either unknown or not considered so long as the

beds seemed conformable and were of the same general lithologic type. With the aid of fossils, however, not only important breaks in deposition came to light, but also constant and easily recognizable differences in petrological characters were found that by themselves enabled the field geologist to distinguish the several parts of the previously supposed unit. Moreover, the fossils rarely failed to substantiate the persistence of the more striking lithological boundaries.

Willis's evident pessimism respecting correlations seems grounded in the belief that the continents, though permanent and essentially stable, were locally affected by periodic but otherwise unrelated movements, and that the continental seas were long enduring, often broad and deep interoceanic waterways, the sediments and faunas of which varied greatly from place to place according to nearness or remoteness from shores and to varying local efficiency of currents. My conception is very different. I see mostly small, shallow, often disconnected basins, occupied at times by Atlantic, and at other times by Gulf of Mexico or by Arctic waters. These were filled and emptied many times, and on each occasion the size and form of the basins differed more or less. As to the continents, I, too, believe they were permanent in general features and that they were affected by many deformative movements, but these movements were always related to a definite, rhythmically progressive plan. Under Willis's view detailed correlations are as impossible, as he believes, because it affords no means of determining the time relations of relatively local physical and organic phenomena to the general scheme of geologic events; under mine definite and often very detailed correlations can usually be made because it is based primarily on the displacements of the strandline which, of all geologic processes, were the most widespread and most nearly simultaneous in their operation. Under his view, again, the local imperfections of the marine stratigraphic column were largely occasioned by fortuitous conditions of uncertain character and relations and not, as under mine, by the periodic retreat and consequent absence of marine waters. Finally, in that it insists on land barriers between continental seas and on the integrity of the invasions from the several oceanic basins, my view, in contradistinction to Mr. Willis', offers sound and efficient reasons for the regional variations of the faunal aggregates.

Summary of diastrophic criteria.—Concisely stated, the criteria of diastrophism embrace all physical, and to a certain extent all organic, phenomena implying horizontal and vertical movements of the crust of the lithosphere. These deformative movements were not always in opera-

tion at the same time, or entirely similar in degree of activity and in character of effects produced, on different continents. They varied also very greatly in intensity and character on different parts of the same continent. Often one part was in course of submergence while another remained emerged or was being elevated. The broader of such diverse movements are indicated more especially as affecting the continents in a north-south direction, but tilting, usually more limited in scope, occurred frequently also in other directions. The alternating Arctic and Gulf of Mexico invasions which, as partly described in preceding chapters of this work, occurred during the middle Ordovician, Silurian, and Devonian, are good examples of the broader differential movements.

Again, in certain parts of the continents, as for instance in the lands bounding the Arctic sea and in the broad median flats of North America, movements in either horizontal or vertical directions were relatively slight. Indeed the former were so broadly disseminated that their local manifestations are scarcely determinable. The vertical movements of these regions were similarly wide in their operations, but in this case, though the maximum vertical displacement was perhaps never very great, their ultimate effects on the size and pattern of the continental seas were manifestly of great and patent consequence.

Though all parts of the crust were affected, nearly the whole of the conspicuous orogenic results of the movements are confined to tracts adjacent to the borders of the continents; and in these the north and south trending orogenic wrinkles increase in development from the poles toward the equator. On the whole, further, the results of the east-west movements are greater on the west borders than on the east. There were also north-south movements of equal and possibly greater magnitude. These resulted in excessive folding and mountain building. The resultant ranges have a generally east and west trend, and were best developed in belts bordering the Gulf of Mexico in the western hemisphere and the Mediterranean and Indian Ocean in the eastern. These north-south movements differed from the east-west, in that while they caused land elevation in the belts mentioned, concomitant subsidence occurred in the Polar regions.

CATEGORICAL REVIEW OF PRINCIPLES OF CORRELATION BY DIASTROPHIC MOVEMENTS

General statement.—The principles discussed under this heading are inferred from physical phenomena and criteria indicating vertical and horizontal movements of or within the shell of the lithosphere and consequent shiftings of the strandline. The following categorical state-

ment of these principles is confined to those which are more or less clearly suggested by criteria and examples discussed in foregoing parts of this work. Though making no pretense to exhaustive enumeration it is yet believed that adequate treatment has been given to all such criteria that have been shown to have a practical value in modernized field studies of stratigraphy. To avoid repetition the several principles are illustrated so far as practicable by reference to descriptions of suitable examples on preceding pages.

The principles are divisible into two groups: (*a*) those based on manifest stratigraphic relations and (*b*) those inferred through deductive reasoning.

Principles based on manifest stratigraphic relation—(1–8) Correlation by unconformities, overlaps, and determinable values of hiatuses.—(1) A stratigraphic unconformity indicates an interruption of the process of sedimentation. Usually, too, it implies emergence and subaerial erosion during the period of such suspension.

(2) A stratigraphic overlap similarly denotes a preceding cessation of deposition and as a rule also submergence or resubmergence of the area thereby transgressed.

(3) Neither the relative discordance in dip nor the degree of irregularity of an unconformable contact is proportional to the time value of the stratigraphic hiatus. The discordance of the unconformity is small or greater according to varying local or regional conditions, hence all unconformities vary more or less decidedly in this respect when followed from place to place. The discordance may be almost imperceptible and always is smaller in the broad interior areas of flat-lying formations than in areas lying within or adjacent to the inland migrating submarginal belt of active folding (see pages 435 to 442 and figure 17, A and B, page 450). The irregularity of the contact, on the other hand, depends largely on the solubility of the surface rock and on such other factors as surface contour and climatic conditions, all of which affect the rate and method of rock decomposition and erosion. Under favorable circumstances a land surface may become very irregular in a geologically brief time, while under less favorable conditions the efficiency of erosional agents is correspondingly reduced. The first condition is illustrated by rapid local erosion of the Girardeau limestone at Thebes, Illinois, where wave-action—an erosional agent but seldom clearly suggested in Paleozoic unconformities—seems to have formed a cliff of this limestone before its fauna was replaced by that found in the limestone which usually succeeds the Girardeau in this vicinity. The second con-

dition is indicated by most of the overlaps found on the flanks of the Cincinnati and Nashville domes. (See pages 305 to 307 and 416 to 419.) Examples of surface irregularity due to solution are seen in the sink-holes in the Ozarkian rocks of southern Missouri. Some of these solution cavities were filled by Sylamore sandstone, others by Osage limestones, and more of them by later Tennessean (Carterville) and Pennsylvanian (Brentwood and Cherokee) deposits.

(4) Conspicuously irregular contacts in interior areas, between Paleozoic formations in particular, denote relatively short periods of emergence, because long emergence tends to baseleveling and consequently to smoothed surfaces that are often difficult to distinguish from ordinary bedding planes. Examples mentioned in the preceding paragraph will serve also in illustrating this principle.

The time value of a stratigraphic hiatus is usually suggested and often clearly indicated by fossil evidence, the local sequence of faunas being compared with the composite standard. However, as this composite faunal record is far from complete and ever in need of corroboration and emendation, it is always desirable to procure all possible stratigraphic evidence that may have a bearing on the problem. Most of the recent additions to the time scale have been occasioned by such stratigraphic investigations.

(5) The local time value of a stratigraphic hiatus is determined primarily by the number and respective values of the intercalated beds or formations that are found on tracing the unconformable contact in the direction from whence the overlap proceeds. Obviously the time value of the hiatus increases as the overlap advances and decreases in the opposite direction. In the latter direction, as shown in figure 17 D, on page 450, the hiatus may split up into a number of smaller hiatuses; or when it is followed in the locally prevailing direction of overlaps—that is, shoreward—two or more planes may converge into a single, correspondingly more important, unconformity.

In the case of formations overlapping two or more preexisting embayments, or a folded and subsequently baseleveled area (see figue 17 A, page 450), the time value of the hiatus varies from place to place. In all cases the maximum determinable value of the hiatus, so far as this can be established in the accessible area covered by the overlapping formation, is the aggregate value of the beds comprised between the base of the oldest and the top of the youngest of the intercalated formations. The complete solution of the more important problems generally involves also the next principle.

(6) The relative ages of formations confined to adjacent but structurally and faunally distinct troughs or basins may often be determined accurately by means of overlapping stratigraphic units. In some cases the formations whose ages are in question are limited above and beneath by respectively younger and older formations whose geographic distribution embraces both basins. This condition, however, does not prove that the intervening formational units are of the same age. It establishes only that they fall within the time interval that began immediately after the close of the lower and terminated before the beginning of the upper of the two more widely transgressing formations.

Further evidence in such cases must be sought elsewhere. As a rule the two formations are finally proved to be of different ages. In some instances differential oscillation has elsewhere brought the two into superposition. More commonly, perhaps, the solution of the problem is found in an intermediate formation or member that transgresses from one area in which it overlies one of the questioned formations to another in which it underlies the second. Examples of both conditions are brought out by comparison of sections in the Athens and Knoxville troughs in east Tennessee.

Thus we find that the interval between the Lenoir limestone and the Tellico sandstone, which formations are present in both troughs, is filled by the Athens shale in the Athens trough and by the Holston marble in the eastern half of the Knoxville trough. Thus confined, the Athens and the Holston seem to hold the same stratigraphic position. Without further information, it would be impossible to prove that they are not also contemporaneous formations and that the former is not a near-shore facies of the latter. Traced northward, however, we find the equivalent of the basal part of the Athens shale resting on the Murat limestone, which, if we may rely on faunal and lithologic identity, is a continuation of the Holston.

The second condition may be illustrated by comparing the lithologic sequence of Ordovician formations in the Athens trough, namely, Mosheim and Lenoir limestones, Athens shale, and Tellico sandstone, with that in the northwestern part of the Knoxville trough, as in Hawkins County, where the Mosheim is followed by the Holston limestone and this by, first, the Ottosee shale and then the calcareo-argillaceous or arenaceous Moccasin formation. Disregarding refined faunal and lithological evidence, it might be supposed that the Athens is the equivalent of the Ottosee and the Tellico of the Moccasin. That neither supposition is correct is proved by the fact that in Knox County the Tellico wedges between the Holston and the Ottosee.

Considering the frequency of proved cases like the foregoing, it may well be questioned if it is not more reasonable to assume difference in age rather than contemporaneity of formations in neighboring troughs which, while seemingly holding corersponding stratigraphic positions, differ appreciably in faunal and lithological respects. In the case of the Ordovician formations in the southern Appalachian Valley, at least, none of the five formations with decidedly Atlantic faunas (Lenoir, Holston, Athens, Tellico, and Ottosee) can be positively shown to have been laid down at the same time when basins immediately to the west were occupied by Gulf of Mexico waters. On the other hand, four of them, the Ottosee shale, the Tellico sandstone, the Athens shale, and the Holston marble, certainly date from times when the basins of the Ohioan province were in a state of emergence. (See discussion of principle 17, page 554.) Regarding the remaining Lenoir limestone, it is only because decisive data are not yet at hand that it is provisionally correlated with the most likely formation in the long standardized section of the Ohioan province. In doing so we tacitly assume the existence of a land barrier between their respective seas. Though the boundaries of the Paleozoic Appalachian troughs always were potential barriers, it yet appears that their functions were called into play less commonly to separate two neighboring contemporaneous seas than to form low ridges on and frequently along the shore of larger land masses in which they were then included.

(7) Interfingering overlaps in areas alternately submerged by waters invading from different oceanic basins are of the highest importance in disproving suggested contemporaneity of formations that seem to hold like positions in the stratigraphic column. This principle is illustrated on a broad scale by the interlapping edges of southern Atlantic and Arctic Ordovician and Silurian formations in eastern Missouri, Kentucky, and middle Tennessee. (See pages 367, 422, and figure 8, page 407.) Similar illustrations are seen on the north and south flanks of the interior domes, which, on account of differential oscillations, have been tilted sometimes toward the east, at other times toward the west. (See pages 415 to 419.) The latter examples are on a smaller scale than the first, but, like them, are relatively simple. More intricate examples are found in the Appalachian Valley.

(8) That diastrophic movements resulting in long emergencies have occurred between two lithologically similar, adjoining, and apparently conformable stratigraphic units may often be established by the discovery of intercalated formations. Examples are given in discussing the lithological aspects of this principle on pages 526 to 532.

Principles based partly or wholly on inference—(9) Relation of areal extent and thickness of formations to rate of submergence.—Great areal extent of relatively thin formations in which progressive diminution by overlap is very gradual indicates rapid submergence of broad, flat areas, shallow seas and low lands, and is marked by extraordinary uniformity of faunas. The best examples are among the Arctic and north Atlantic invasions, of which the Decorah shale and the Prosser limestone extend southwardly to or beyond Missouri. (See pages 367 to 371.) Even more extraordinary than these is the late Richmond coral zone, which is recognized in Russia, Baffinland, in Alaska and as far south in the Mississippi Valley as Thebes, Illinois, and in the Cordilleran basin to New Mexico and western Texas. (See page 306.) Of the numerous southern invasions those that transgressed widely and rapidly are the Lowville, the late Eden, the Brassfield, the Osgood-Rochester, and the Onondaga.

Thick, geographically limited formations, especially those which consist chiefly of land detritus, indicate relatively high relief of lands and deposition confined to the continental shelf and to relatively deep and narrow submarginal troughs. Such are most of the Paleozoic formations exposed between the shore of the Atlantic and the Appalachian Valley, and the similarly located formations on the western side of the continent.

(10) Correlation by evidence of sea-filling and tidal flats.—Suncracked and ripple-marked marine deposits, also intraformational conglomerates and worm-bored surfaces, found singly or together, indicate either sea-filling and, consequently, shallowing of seas and impending emergence, or the advance of a shallow sea over broad tidal flats. In the former cases these phenomena occur in the closing stage of a period of uninterrupted sedimentation; and the development of the individual beds so marked is often decidedly local; for example, the local occurrence of sun-cracked and rippled surfaces in the upper part of the Pamelia Stones River in the vicinity of Kingston, Ontario. A broader example of shallowing preceding a long emergence is found in the very widely distributed late upper Cambrian zone which is commonly marked by thin beds of "edgewise" intraformational conglomerates. Although this zone is very generally distributed, the individual beds of conglomerate are very limited in areal extent. In the alternative cases, wherein the phenomena are produced under conditions of sea transgression over tidal flats and beaches, the characteristically marked beds or surfaces are, as a rule, much more extensive. Good examples are seen in the lower and middle parts of the Lowville limestone in the Appalachian

Valley south of central Virginia; also in the Wills Creek, a Cayugan formation in Maryland and Pennsylvania.

(11) Correlation by evidence of progressive submergence.—Conglomerates and the various other initial deposits described on pages 454 to 456. usually indicate progressive submergence of a preceding land area. This interpretation, however, is permissible only so long as these deposits follow a determinable stratigraphic hiatus. Exceptionally they may occur during the course of otherwise uninterrupted sedimentation (see figure 17 E, page 450) as when land-wash for some climatic reason is temporarily increased. Again, they may be formed along the shore of a restricted sea, providing of course that conditions favoring transportation of land detritus obtain in the affected areas. In all such exceptional cases the stratigraphic relations of the clastic deposit are peculiar in that the bed wedges out in an unbroken sedimentary sequence.

(12) Change in character of sediments indicative of diastrophic movement.—Abrupt or even relatively gradual changes in kind of sediment, especially if the change is from limestone to some distinctly clastic deposit, always suggest diastrophic activity. This may be entirely local in its immediate origin and extent. As a rule, however, the change is connected with some broader deformative movement which may result in similar effects in many places or in dissimilar—often, indeed, directly opposite—effects in widely separated regions. Obviously there is no sharp line of separation between local and general movements, and as the lithological and structural manifestations are very similar in both, it is often very difficult to decide between them. Further, while marine sandstones frequently succeed limestone, we know also that wind-blown dune and beach sands, and more rarely ordinary fluviatile and delta deposits, similarly rest on limestone. And are we not certain that the lithologic change is sometimes occasioned by local climatic changes having no immediate connection with decided orogenic or epeirogenic movements? Even if I were capable of doing justice to this phase of the subject, the task would be far beyond the scope of the present work. All I wish to bring out here is the necessity of close investigation of all lithological changes in local stratigraphic sequences, because they are richly promising in the search for stratigraphic breaks. The discovery of such breaks, whether previously suggested by faunal evidence or not, is the most important duty of the progressive stratigrapher. There is always the chance of finding some new, previously unrecognized stage in geologic history.

So far as the evidence in hand will permit of forming an opinion, the

great lens of Athens sandstone described by Hayes[71] as occurring in the body of the Athens shale in Polk County, Tennessee, is due to some local cause. No similar change in deposition, from black shale and limestone to sandstone, is known to have occurred at this time in any other part of the Appalachian Valley. It may possibly be contemporaneous with movements and consequent displacements of the strandline in more interior regions, but we have no means of proving such connection.

Thin sandstones in the late Chazy to middle Black River sections in the Ottawa River Valley may also have only local significance, but it is thought likely that they bear genetic relationship to movements in the middle and northern Appalachian Valley that opened the way for transgressions of the Lowville sea.

The transition from the Everton limestone to the Saint Peter sandstone in northern Arkansas, as described on page 479, is perhaps the best example of the rare phenomenon of sandstone deposition following limestone without interruption of the process of sedimentation. In the great majority of cases in which a clastic deposit succeeds a pure limestone cessation of deposition intervened.

(13) Differential effect on strandline in continental tilting.—Elevation and consequent sea withdrawal, whether due to orogenic or epeirogenic movements, may occur on one side of a continent while the opposite side is subsiding. Hence in such cases emergences and stratigraphic hiatuses on the former side are to be correlated with submergences and resulting deposits on the latter. This condition may have obtained occasionally if not commonly with respect to the east and west sides of a continent, but the reasons why it might are not so convincing and the stratigraphic facts on which the demonstration of the proposition must chiefly rely are not so clearly expressed as in the case of the north and south sides. The theory is explained on page 406 and its operation illustrated by figure 8. The stratigraphic evidence on which it is founded is brought out in discussing the distribution of Ordovician and Silurian formations and faunas which invaded alternately from the north and south (see pages 367 to 371 and 558 to 561). This extremely important principle applies mainly to correlations implying broad continental tilting. The next following is concerned more particularly with relatively local oscillations.

(14) Correlation implying local tilting and warping.—Differences in the stratigraphic sequence on opposite sides of structural domes or in neighboring troughs, also local peculiarities in sequence, generally denote differential oscillation and warping of the earth crust and consequent

[71] C. W. Hayes: Geol. Atlas U. S., Cleveland folio, 1895.

irregular shifting of continental seas. The evidence on which this principle is postulated is unusually abundant and when fully published it can not fail to be convincing. Much of it is described on pages 411 to 430. This discussion, however, is of necessity largely confined to generalized statements, the detailed observations on which many of the asserted correlations are based being reserved for publication elsewhere.

(15) Correlation by probabilities depending on rhythm of movements.—Breaks in local stratigraphic sequences having been established the time relations of the hiatuses in different areas, as in adjacent structural basins or in distinct faunal provinces, are usually determined by fossil evidence. However, often this evidence is inconclusive and sometimes even misleading, and provisional conclusions pending discovery of localities where such relations are positively manifested are frequently desirable. In such cases we may correlate on the basis of probable changes in the attitude of continental basins with respect to sealevel during the rhythmic course of diastrophic movements. When the crude and regionally varying rhythm has been sufficiently ascertained it seems possible to predict which trough or troughs in the Appalachian Valley, for instance, are likely to have been submerged at a certain time and which remained emerged. The stratigraphic hiatus in the latter is thus correlated with a deposit in the former. The principle also contemplates correlation by probabilities suggested directly and solely by the known or inferred extent of continental seas at given times.

The application of this principle in correlating disconnected deposits and stratigraphic breaks in adjacent troughs presupposes detailed knowledge concerning the distribution of beds and faunas in the area affected by the oscillatory movements. Such an area would be the Appalachian Valley in east Tennessee, where the areal distribution of fifteen or sixteen successive Ordovician zones and formations, beginning with the base of the Stones River and ending with the calcareous Cincinnatian sandstone commonly referred to as the Bays, is fairly well worked out. In this area the age of a bed lying between two previously recognized formations may be quickly decided. For instance, in the west Knoxville and Pearisburg troughs, a fine grained limestone, in contact with the Knox beneath and the Holston above, would be at once referred to the Mosheim. And this reference would be justified not only because no other limestone is known to occur in this position in those troughs, but also because in the development of the Stones River oscillations only the lower or Mosheim division spread entirely across the valley. Following the Mosheim the middle troughs were emerged so as to separate the

TABLE SHOWING EAST-WEST SHIFTING OF ORDOVICIAN SEAS IN THE APPALACHIAN VALLEY TROUGHS IN EAST TENNESSEE.

SILURIAN			Gulf of Mexico Invasions	Newman Trough	Clinton Trough	Pearisburg Trough	West Knox or Copper Ridge Trough	East Knoxville Trough	Athens Trough	Atlantic Invasions
CINCINNATIAN	Maysville	General emergence		* * *	* * *	* * *	* * *	* * *	* * *	
		Upper "Bays" or Fairmount	—	—	—	—	—	— ? —	— ? —	
	Eden	Middle and Upper Eden (Sevier)	—	—	—	—	—	— ? —	— ? —	
		Utica emergence	* *	* * *	* * *	* * *	* * *	* * *	* * *	—
MOHAWKIAN	Trenton	Catheys	—	—	—	* * *	* * *	* * *	* * *	*
		Perryville	—	—	—	—	* * *	* * *	* * *	*
		Bigby	—	—	—	—	—	* * *	* ? *	*
		Wilmore	—	* * *	* * *	* * *	* * *	* * *	* ? *	
		Hermitage (Upper Moccasin, Bays)	—	—	—	—	—	—	—	?
		Middle Moccasin (? Stewartville, Prosser)	*	* * *	—	—	—	—	* ? *	?
	Black River	Lower Moccasin (Kimmswick, Chambersburg restricted	*	* * *	—	—	* * *	* * *	* ? *	?
		Decorah and Amsterdam	—	—	* * *	* * *	* * *	* * *	* ? *	?
		Watertown	—	—	* * *	* * *	* * *	* * *	* ? *	?
		Lowville (locally including a lower Moccasin)	—	—	—	—	—	* * *	— ? —	?
CHAZYAN	Blount	Ottosee	*	* * —	—	—	—	—	—	—
		Tellico	*	* * *	* * *	* * *	* * *	—	—	—
		Athens	*	* * *	* * *	* * *	* * *	* * *	—	—
		Holston	*	* * *	* * *	—	—	—	* * *	—
	Stones River	Pamelia	—	—	* * *	* * *	* * *	* * *	* * *	*
		Middle Stones River and Lenoir	—	—	* * *	* * *	* * *	—	—	—
		Lower Stones River or Mosheim	—	—	—	—	—	—	—	*
		General emergence	*	* * *	* * *	* * *	* * *	* * *	* * *	*

Heavy lines indicate presence, stars absence, of respective sediments.

middle Stones River sea on the west from the Lenoir limestone bay on the east. Next the Lenoir bay was entirely drained and subsequent late Stones River deposition confined to areas west of the Clinton trough. The general emergence which terminated the Stones River was followed by the Holston submergence of the valley troughs. To the south of the Knoxville parallel the Holston marble is confined to the Knoxville troughs, but northward from this city a thin crystalline limestone, provisionally referred to the Holston (it may belong to the Ottosee), transgresses these boundaries and overlaps as far as the Newman trough in Hancock County. As shown in the accompanying table, the succeeding Ordovician seas shifted back and forth across the valley, but the shifting seems always to be in accord with a definite plan. Additional information respecting the migration of Ordovician seas in the Appalachian Valley is brought out in the discussion of principles 17 and 18.

Judging from the known and inferred extent of post-Clinton Niagaran seas in southeastern North America, it is thought quite improbable that any marine deposit of this age will ever be found in the Appalachian Valley from Lake Champlain to Alabama. Under this belief the Sneedville limestone in Hancock County, Tennessee, a formation long ago referred to the Niagaran by Safford, was investigated and shown to be post-Niagaran—probably Manlius—in age. Also, the beds in Maryland, now known as the McKenzie formation, which Schuchert in 1903 and others since then have referred to the Niagaran, were studied recently and proved to be of Cayugan age.

On the other hand formations have been recognized in areas where their presence was originally suggested on theoretic grounds. For instance, everything seemed to support the belief that the upper Stones River sea extended northward into north central New York. The validity of the suggestion is now established, Cushing (1908) having described and proposed the name Pamelia for the upper Stones River limestone in that State.

Many such verified predictions based on inferred probabilities respecting the geographic pattern of Paleozoic continental seas might be cited, but those mentioned, it is believed, will suffice to illustrate the principle. The matter of rhythm in recurrence of geological phenomena is rather fully discussed in Part III (pages 599 to 607).

(16) Correlations implying complete emergence of continents at frequent intervals.—General emergence of continents to approximately their present and occasionally even greater dimensions is believed to have occurred at the close of each period and probably also at the close of

many of the smaller divisions of the geological time scale. This belief is based on evidence of interruption of sedimentation at such times in the fullest depositional records, hence, presumably, in the deepest parts of the continental basins now accessible. In passing, it is to be said that in the facts chiefly relied on in reaching this conclusion lies also the strongest of the arguments favoring the idea of essential permanence of continents and oceanic basins.

Though subject to local variation due to surface tilting and consequent shifting of continental seas and, aside from that, not by any means consistently carried out through all the ages, it is nevertheless a fact that many of the thickest known sections of a given time are found in the same structural province in which other formations attained their maximum development. It is true, also, that other regions are distinguished by prevailingly thin depositional records. These are areas in which stratigraphic overlaps are common and in which, therefore, positive tendencies are dominant. In the former, on the contrary, negative tendencies prevail. Departures from the rule of prevailingly thick deposits in negative areas probably are due primarily to the varying meter of the rhythmically recurring expression of diastrophic movements. At times the movements which resulted from suboceanic spreading seem to have been deeper seated than usual and to have reached the surface farther inland causing continuance of emergence, as in the Appalachian Valley during middle Silurian, where submergence would otherwise be expected. Secondary causes may have been the inland migration of the belt of active folding (see pages 435 to 442) and accumulating irregularities in structure caused by uneven distribution of sediments, their varying resistance to deformation and original local differences in specific gravity. All of the last causes would tend to obscure the rhythm of the movements as expressed by displacements of the strandline; and obviously this obscuration became more and more effective with time. Finally, old warps may have been periodically accentuated in one case, causing elevation and merely increased emergence, while in another the subsidence of the downwarp may have been insufficient to bring the deepened trough beneath sealevel. In either case the record might be undecipherable. (See page 425.)

The great Cordilleran basin evidently is the oldest of the post-Archean geosynclines and the first to receive marine sediments. Here we find a great series of pre-Cambrian deposits, the like of which is not seen elsewhere in America. This was followed in other parts of the basin by the greatest known sequence of Cambrian sediments, and these more locally

by very considerable thicknesses of Ozarkian and Canadian limestones. Beginning earlier than the genetically similar Appalachian trough, the Cordilleran syncline, also reached early in the Ordovician a stage of predominating emergence that may be likened to the mid-Silurian emergence of the Appalachian syncline. Except along its western edge, where graptoliferous shales were locally deposited, this emergence of the Cordilleran troughs seems to have continued with only slight interruptions (late Black River or early Trenton and again in the Richmondian) through nearly the whole of the Ordovician and Silurian periods. Neopaleozoic deposition was resumed here in the Devonian, extraordinary thicknesses of limestone belonging to this era and to the Pennsylvania system of the succeeding era being laid down with relatively brief interruptions of the process.

In the Appalachian geosynclines marine sedimentation probably began some time after the beginning of the oldest lower Cambrian. Here, as in all the continental basins, the process of sedimentation was interrupted at times. The durance of these interruptions varied from time to time, and more particularly from place to place, the relatively brief general emergences expanding locally into much greater discontinuities. In the aggregate, however, the stratigraphic sequence after it began here is more nearly complete than in the Cordilleran trough. There we find a more continuous Cambrian record, but here the succeeding three systems of the Eopaleozoic are, so far as known, much better developed, and therefore better fitted to fill the requirements of a standard for America and the world.

During most of the Paleozoic ages the Appalachian and Cordilleran geosynclines most probably comprised the lowest ground in North America. This view is based on the undeniable fact that these troughs were often longer, and in many cases sooner, occupied by marine waters than any other area of which we have knowledge. Granting the validity of the argument, it follows that when these troughs were completely drained the emergence must have extended as a rule to all the remainder of the continent. The exceptions occurred only when the depositional record in these great synclines was inferior to that found elsewhere. The only notable exceptions are the late Ozarkian, the earliest Ordovician, and the middle Silurian (Chicago) ages.

On the basis of these premises, it seems fair to assume as established, that the sea withdrawal indicated by a stratigraphic and faunal break at the top of the thickest known deposit of a given age in the Appalachian Valley or elsewhere also affected all other parts of the continent then or

before resubmergence set in. Such a break, providing the base of the overlying formation is the oldest deposit of its age known, establishes further that this withdrawal, and the emergent condition following it, occurred during a distinct interformational period, the depositional record of which, if not wholly confined to the oceanic basins, is at least completely buried beyond present accessibility. If the top bed of the underlying formation is not its youngest, then the question whether the first deposits above the break are or are not equivalent to strata elsewhere referred to the top of the underlying formation may remain unanswered. If fossil evidence on the point is inconclusive principles 15, 17, and 18 may help in deciding the question. Similarly the solution of the problem remains incomplete when a formation at its maximum is succeeded by other than the oldest beds of an overlapping formation. The following examples will illustrate the principles and bring out the differences between the three conditions alluded to. It is to be observed that the principle applies in essentially the same manner in establishing extensive emergence between stratigraphic units, whether their rank be that of a system, series, group, or formation. The first example throws very interesting light on the time value of the new Ozarkian system and on its stratigraphic relations to the Cambrian.

The Ozarkian illustration.—The Ozarkian system as developed in the southern part of the Appalachian Valley comprises the various magnesian limestone formations which succeed the last of the upper Cambrian shales and thin limestones, and precede the Canadian limestone or, where that is absent, the Stones River limestone of the Ordovician system. The whole of this sequence of dolomites and magnesian limestones is commonly referred to a single great formation—the Knox dolomite. However, this composite Knox varies greatly from place to place in its thickness and in the age of the beds contained in it. In Knox county, Tennessee, where the formation was first studied and from which it was named, the Knox consists mainly of a characteristically and profusely cherty middle division to which I am applying the name Copper Ridge chert. This is flanked above and beneath by much thinner and very sparingly cherty members, for which no names have been proposed. This being the typical Knox, and as all the other beds commonly referred to the Knox are readily distinguishable, it seems advisable to confine the term to it. At its maximum, as observed in Hancock County, Tennessee, a few miles south of Sneedville, the typical Knox attains a thickness of about 3,400 feet. At other localities, however, the upper and lower members are thicker than here, so that the aggregate maximum of these divisions is considerably greater. (See Part III, pages 633 to 640.)

The so-called Knox of the northeastern part of the valley of east Tennessee, as at Jonesboro and in Tuckaleeche cove, is a totally different formation, being noncherty, less magnesian, altogether younger, and apparently wholly referable to the Canadian system. To the south in Alabama another formation about 1,000 feet thick, characterized by abundant, soft mealy chert, and for which the name Chepultepec is elsewhere proposed, is intercalated between the top of the typical Knox and the overlying Canadian limestone and dolomite. Between Pelham and Helena and in the vicinity of Montevallo all three of these formations are present but at Chepultepec, in Blount county, Alabama, the upper is absent, the Chepultepec there being in contact with the Stones River.

Sections in Alabama add important formations also to the base of the Ozarkian. In the Birmingham Valley some hundreds of feet of very pure dolomite, to which Mr. Charles Butts of the U. S. Geological Survey has applied the name Ketona, underlies the typical Knox. About midway between Birmingham and Montevallo, according to recent investigations by Mr. Butts, another, but highly siliceous, magnesian limestone, attaining a thickness of over 1,000 feet, wedges between the Ketona and the sharply defined top of the underlying thin-bedded upper Cambrian limestone of the Conasauga formation. Not only is a new Ozarkian formation intercalated, but both the overlying Ketona dolomite and the underlying Conasauga limestone are thicker than usual. Moreover, a few miles farther south a third, also highly siliceous, magnesian limestone, is intercalated between the top of the Ketona and the base of the typical Knox. This third addition to the lower part of the Ozarkian is lithologically very similar to the Potosi dolomite of the Missouri section. As the two seem also to agree exactly in stratigraphic position, the same name might justly be applied in both areas.

The lesson taught by the Ozarkian in east Tennessee and Alabama is that the break between the Knox and the upper Cambrian in the vicinity of Knoxville is greater than it seems. In fact, by the time one has reached Montevallo he will have learned that the break represents more than 2,500 feet of dolomite. I say more because the break at the top of the Cambrian remains in evidence as far south as the formation can be seen—that is, to the edge of the Cretaceous overlap. Now if this break implies, as I have no doubt it does, that sea withdrawal occurred at the close of the Conasauga Cambrian, and as we have no record of intermediate deposits elsewhere in eastern America, it is justly inferred that the resulting emergence affected the whole of the valley and probably the whole

continent. Furthermore, since the intercalated formations are progressive overlaps and there is little or no reason to believe that the top of the underlying Cambrian formation—represented by the Conasauga in the south and the Nolichucky and Honaker formations in Tennessee and Virginia in the north—varies greatly in age, it follows that pre-Knox erosion had little to do with the noted differences between the sections at Knoxville, Tennessee, and Montevallo, Alabama. If anything, the top of the Nolichucky in places is younger than any observed surface of Conasauga. Aside from this, the stratigraphic hiatus is much greater in Tennessee and farther north in the valley than in the vicinity of Montevallo.

The essential features of the foregoing example are duplicated in all the systems that are well developed in the Appalachian Valley or in adjacent parts of the Allegheny basin. They are similarly well displayed by the Cambrian, the Canadian, the Ordovician, the Devonian, the Tennessean, and the Pennsylvanian, all of which, save the Cambrian and most probably also the Ordovician, have older beds at their respective bases than are known elsewhere in American continental basins. It is to be admitted, however, that on account of oscillation and shifting of seas, the data necessary to a complete demonstration of the proposition in these other cases are usually not found in the same area, correlation by fossils and lithologic criteria and by stratigraphic overlap being required to establish the sequence. The Silurian fails because it is less completely developed in the valley than the others. The same may be said of the Waverlyan.

Complete emergence at close of Pamelia Stones River.—The principle of complete emergence applies in a similar manner to many of the diastrophically separated formations; obviously, then, to the groups and series also. As an example, we may take the Pamelia-Lowville break—the latter formation a middle Ordovician datum plane often referred to in this work. The time value of this break is more fully discussed under the next principle.

Wherever known, the Lowville is terminated below by a sharp break. Where the formation rests on some bed of the lithologically similar Stones River formation, as happens very commonly, this break is seldom conspicuous, however sharp it may prove to be on close investigation. But when the Lowville rests on the upper Chazy or its equivalent, as at Chazy, New York, and at Mercersburg, Pennsylvania, or on either the Holston or the Ottosee, as we find it in Hancock county, Tennessee, the contact is not only sharp, but also conspicuous and clearly indicative of inter-

rupted sedimentation. The significance of this fact is apparent when we realize that, in addition to the Holston, three other east Tennessee formations—the Athens shale, the Tellico sandstone, and the Ottosee formation—as shown in the table on page 544 and more fully described on page 555, are intermediate in age between the Stones River and the Lowville. The Hancock County occurrence may seem especially significant in this connection, because here the Lowville attains a thickness of over 400 feet, which is the maximum for areas in which the upper Stones River is present; also, because the areal distribution of the Lowville and the Holston in Tennessee is widely different, hence indicative of oscillation and sea-shifting between the two formations. Sea withdrawal being established between the oldest known Lowville deposits and the youngest of the upper Chazy or Holston beds in the Appalachian Valley, and no deposits of intermediate age being recognized elsewhere in America west of the Appalachian Valley barrier (see map, page 293), the conclusion seems inevitable that practically the whole continent shared in the intervening emergence.

Similarly extensive emergences are indicated by the same kind of evidence at the close of the Black River group, the close of the Helderbergian, the Ozarkian, and the Saint Louis. The emergence at the close of the Clinton doubtless was no less widely effective, but the evidence in this case is only partly recorded in the Appalachian Valley. Besides these, many other withdrawals are more or less clearly indicated by detailed stratigraphic studies in southeastern North America. A considerable number of these may have been quite local or perhaps provincial in scope, but in others again the emergence seems to have been general, not to say continental, in extent.

The Ozarkian-Canadian emergence.—The relations of the Canadian and Ozarkian formations in central Pennsylvania will serve to illustrate the course pursued in proving complete withdrawal of the sea from the Appalachian Valley basins at the close of a system whose upper beds are known to be wanting in the immediate area of a succeeding full systemic sequence—in other words, when the fact of such withdrawal at the close of the older system may be established only by correlation with sections elsewhere in which the missing later deposits of the same are present. The example to be discussed is exceptionally difficult, and the complete solution of its problems as yet impossible, first, because the youngest Ozarkian formation, namely, the Jefferson City dolomite of the Missouri section, is nowhere recognized in the Appalachian Valley, and, second, because of the uncertain relations of the first Canadian de-

posits (Phyllograptus bed) in northern Arkansas to the formations of the same period in central Pennsylvania.

At Bellefonte, Pennsylvania, the greatest known development of Canadian limestones is excellently exposed. The four formations, named from below upwards the Stonehenge limestone, the Nittany dolomite, the Axeman limestone, and the Bellefonte dolomite, into which the Canadian is here divisible, have an aggregate thickness of over 4,200 feet. The lowest of these, a nearly pure limestone, rests on the Kittatinny formation, which is determined on stratigraphic and faunal evidence to be early Ozarkian in age. The sequence, therefore, is incomplete, middle and upper Ozarkian deposits being absent. Traced southward along the strike, a part of the missing beds is found. South of Roaring Spring, namely, where the Kittatinny is more fully exposed, a thick northwardly overlapping wedge of middle Ozarkian chert is intercalated between the Kittatinny and the base of the Canadian formations.

In the further pursuit of the inquiry we are obliged to resort to other criteria usually employed in correlating formations. Relying chiefly on fossil evidence, we know that the Chepultepec zone of the Alabama Ozarkian section is represented at the top of the Little Falls dolomite in New York, and that this zone is there separated by an unconformity from the Tribes Hill limestone, which is correlated on good faunal grounds with the Stonehenge formation at Bellefonte (Ulrich and Cushing, 1910). The persistence of the unconformity at the base of the Stonehenge-Tribes Hill zone proves complete emergence of the Appalachian Valley at the close of the Chepultepec, which is the last of the Ozarkian deposits therein laid down.

The completion of the chain of evidence on which continent-wide emergence during an Ozarko-Canadian interval may be fairly inferred requires only that it be shown that the highest known Ozarkian—the Jefferson City dolomite of the Missouri section—is not of the age of the Stonehenge and Tribes Hill limestones, but that it belongs in the hiatus between these limestones and the Chepultepec zone.

Unfortunately, so far as known, all three of these zones are nowhere superposed. We do know, however, that the Jefferson City is younger than the Chepultepec, the fauna of the latter being under the Jefferson City, in Missouri. We know, also, that in northern Arkansas the Jefferson City is separated by an unconformity from the overlying Yellville Canadian; but the exact position of the lowest Yellville zone in the Canadian section of central Pennsylvania has not been fully established. The Ozarkian affinities of the Yellville fauna suggest that the formation is early Canadian in age, but as both invaded from the south this re-

lationship may after all be remote, so far as geological time is concerned. Besides, comparison with the Canadian faunas in Pennsylvania and the valley of Lake Champlain seems to antagonize rather than to support this suggestion, the oldest Canadian fauna there being very different, while alliances with the Yellville fauna are apparent only in the Cassin fauna of Division D. Under the circumstances the final solution of the problem is yet a matter of opinion, mine being that the emergence of the Appalachian Valley basins at the close of the Chepultepec continued to the beginning of Stonehenge deposition, and that when the restricted Jefferson City sea was withdrawn the emergence involved the whole continent. Further evidence supporting this opinion will be given in Part III. (See page 673.)

The Canadian-Ordovician emergence.—The evidence on which extensive emergence is inferred at the close of the Canadian in America is similarly intricate, but on the whole more conclusive. The solution of the problem again involves the disposition of a series of deposits in the Mississippi Valley—the Saint Peter sandstone and associated limestones (see page 479)—that can not be identified in the Appalachian Valley. The case differs in that the missing beds are the first instead of the last of the system to which they belong; hence that the Ordovician submergence began in the Mississippi Valley and not in the Appalachian basins.

The Bellefonte dolomite, the last of the Canadian deposits in central Pennsylvania, is succeeded at Bellefonte by upper Stones River. This gap is readily diminished to the extent possible in the Appalachian Valley by comparison with sections at Chambersburg, Pennsylvania, and Martinsburg, West Virginia. In these sections the full Stones River group is represented in a maximum thickness of about 1,200 feet of solid limestone. Its base is in contact with the Beekmantown limestone, the top of which is here very late Canadian in age. That the contact is unconformable and marks a stratigraphic hiatus is indicated by various signs, among them occasionally a thin layer of quartz conglomerate.

The Beekmantown-Stones River hiatus is thought to be represented in part by the Saint Peter series in the Mississippi Valley. In north Arkansas this sandstone series rests with unquestionable unconformity on the Yellville or, where that formation is absent, on the Jefferson City dolomite. There is also an unconformity at the top of the Saint Peter sandstone and of its seaward representative, the Joachim dolomite; but, despite the fact that the overlying beds are either late Stones River or of Lowville age, this unconformity does not impress one as so important as the break at the base. As must be apparent, the evidence is involved,

and the argument fixing the stratigraphic position of the Saint Peter series necessarily too long and many-sided to be set forth at this time. For present purposes it will suffice to say that the problem has been very carefully studied and the conclusion reached that the group or series of formations beginning with the Everton limestone and ending with the Joachim is older than the Stones River and younger than the last of the long sequence of Canadian deposits in central Pennsylvania. Assuming the validity of this conclusion, very extensive emergence at the close of the Canadian is established. The only reason that causes me to hesitate in declaring that this emergence affected the whole continent is my present inability to decide whether certain graptolite shales at Summit, Nevada, fall within this emergent stage or whether they are younger or older. (See page 676.)

(17) The principle of maximum thickness of overlapping formations.—The maximum thickness of an overlapping formation whose distal edge is overlapped from another or perhaps opposite direction by a similar thin wedge (see figure 8) is thought to have been deposited before the land transgression of the second began. Essentially the same principle is involved when two overlapping formations which invaded a given area from the same oceanic basin are directly superposed. In such cases it is thought that the hiatus between the two formations may, as a rule, be interpreted as including one or more intervals in which a corresponding number of invasions from other quarters occurred that failed to reach the locality in question.

This principle is based on the hypothesis of land tilting which, whether of continental or geographically minor extent, assumes that the attitude of the continent with respect to sealevel, or of such parts of it as were affected by the successive overlaps, must have prohibited submergence of, say, the southern part of North America while sea invasion was progressing in the north. The hypothesis assumes further that the reversal of the prevailing general or local tilt was accomplished in the interformational intervals during which marine deposition was confined to epicontinental or extracontinental areas now inaccessible. Remembering that marine deposition requires preceding submergence, apparent exceptions to the rule may be explained by assuming that at such times the reversal of the tilt was insufficient to effect submergence. The absence of Cincinnatian, Silurian and Devonian deposits on the east side of the Nashville dome is explained in this manner on page 425.

Demonstration of the principle by the Lowville overlap.—Though the demonstration of the proposition often rests almost entirely on correlation

by faunal and lithological criteria, it is sometimes possible, especially in the more simple cases, to reach a plausible conclusion without such means. We can, for instance, establish readily enough that the seemingly slight break between the Pamelia and Lowville limestones in New York, Kentucky, and central Tennessee is really of high importance. By tracing the formation southward in the Appalachian Valley, we learn that the Lowville expands by additions to its base to over 400 feet of limestone in Hancock County, Tennessee. In other words, that this formation, like the Stones River before it, overlapped northward so that nearly 300 feet more of limestone than reached north central New York was deposited in the southern locality, and all of it following the close of the upper or Pamelia limestone division of the Stones River group. Unfortunately, the proof that the hiatus between this upper Stones River limestone and the base of 400 feet of Lowville represents, as shown in tabular form on page 544, deposition in the Knoxville and Athens troughs of about 660 feet of Holston marble, 1,000 feet or more of Athens shale, about 500 feet of Tellico sandstone, and 400 to 1,200 feet of Ottosee shale is not so easily procurable. The chief difficulty lies in the fact that the upper Stones River is not found in areas where the Holston attains anything like its maximum thickness. Concerning the relations of these two formations the best evidence now at hand was observed in Mulberry Valley north of Sneedville, Tennessee. Here an 80-foot wedge of crystalline limestone, presumably representing the Holston—which formation seems to have overlapped westward into the Newman trough in northeastern Tennessee—is intercalated between the top of the Stones River and the base of a 400-foot Lowville section. The contact with both of these formations is unconformable. Regarding the lower hiatus in the Mulberry Valley section, may we not assume that it represents emergence while the remaining earlier beds of the Holston were being deposited in the Knoxville trough?

Resorting to fossil evidence and to correlation by stratigraphic position and similarity of lithic characters, this assumption becomes reasonably justified. Despite the great time break between the Stones River and the Lowville, their respective faunas are similar in general respects. But this is explained by the fact that both migrated from the Gulf of Mexico, so that the Lowville fauna comprises many close derivatives or recurrences of Stones River species. The Holston fauna, on the other hand, is very different, being of the north Atlantic type. Now, if this fauna had lived in the middle troughs of the valley at the same time that the late Stones River sea occupied basins to the west, it is inconceivable how intermingling of the two faunas could have been prevented when the

Holston finally overlapped into the Newman trough. But the section in Mulberry Valley shows that the faunas did not commingle. On these grounds alone we would be justified in giving full weight to the evidence of interrupted sedimentation there exhibited by the contact of the Holston wedge with the underlying Stones River.

But we can add something in corroboration of this faunal evidence. Thus, the basal member of the Chambersburg limestone in the vicinity of Mercersburg, Pennsylvania, is over 200 feet thick and confidently correlated with the Holston (see pages 325 to 328). It is sharply defined from the upper Stones River below and from the Lowville member of the Chambersburg above. As these contacts are still unconformable, the contention that the Holston at its maximum is younger than the Pamelia Stones River seems reasonably assured. The case so far and to its final development is a clear illustration of the principle that the hiatus between two important formations which invaded from the same oceanic basin includes an interval during which invasion from another quarter occurred.

It remains to be shown that the Pamelia-Lowville hiatus represents not only the Holston but also the Athens, the Tellico, and the Ottosee. The only feature of this problem that has not been established by positive stratigraphic superposition is the relation of the Athens shale to the Holston; and on this point we have faunal evidence that is satisfactory if not conclusive, namely, the Murat limestone of west central Virginia is an unquestionable extension of the Holston. At Lexington this limestone is succeeded by a very striking fauna of which something like 80 species have been collected. This same fauna occurs at Blacksburg, Virginia, and at Pratts Ferry, Alabama, at the base of the Athens shale.

In the Athens trough of east Tennessee, in which the Holston is absent, the Athens shale is followed by the Tellico sandstone. In both the Athens trough and in the eastern part of the Knoxville trough the Ottosee shale, which has been hitherto referred to the Sevier shale, rests on the Tellico. Though not so thick as at Knoxville, Bulls Gap, and Athens, the Ottosee is yet well and unmistakably developed in the two Ordovician belts between Clinch Mountain and Clinch River in Hawkins and Hancock counties. In both bands the Holston underlies the Ottosee, and over that is the Lowville. The outcrops referred to are located in the northern third of the Morristown quadrangle, and the formations have been mapped by Arthur Keith as Holston marble, Chickamauga limestone, and Moccasin limestone.

In the band lying just north of War Ridge the Holston rests on a very uneven floor of Knox dolomite. In thickness it varies from 0 to 120 feet or more. The Ottosee, which overlies it unconformably, is also

thin and variable in thickness, the observed variations ranging between 35 and 100 feet. Above the latter, apparently again with a stratigraphic hiatus between them, comes a series of fine-grained, thin-bedded limestone, 400 feet to possibly 600 feet in thickness, that is correlated with the Lowville. This determination is made chiefly on the basis of fossils, the lower 50 feet containing fine examples of a fasciculated *Tetradium,* referred provisionally to *T. cellulosum,* and the upper 200 feet *Beatricea gracilis.* This is followed by typical Moccasin. Only the base of the Moccasin is locally exposed, the remainder being covered by overthrust Cambrian deposits.

In the belt to the south of this, between Copper Ridge and Clinch Mountain, the Holston rests unconformably on 84 feet of Mosheim (lower Stones River) limestone. About 660 feet of typical Holston limestone, mostly heavy bedded marbles, is passed over before the first appearance of the Ottosee bryozoan fauna which prevails in the succeeding 470 feet. Though consisting mainly of shales and thin limestones, the Ottosee here includes an 80-foot bed of massive pink marble. Above the Ottosee the section at Thorn Hill exposes 150 feet of argillaceous fine-grained limestone and shale not seen farther east in the same valley. This is believed to represent a part of the Lowville in the War Ridge belt. Some 200 feet or more of the overlying "Moccasin" probably also is of Lowville age. Fossils are few and not very satisfactory, but what there is of them is not opposed to this reference.

Thus, by showing that the Holston succeeds the Stones River; that the Athens shale follows the Holston; that the Tellico lies between the Athens and the Ottosee, and that the Lowville, in its fullest development, rests on the Ottosee, the time value of the Pamelia-Lowville hiatus is established, so far as it is represented by known sediments in the Appalachian Valley.

Demonstration by alternating northward and southward overlaps in the Mississippi Valley.—The best illustrations of interfingering of distal edges of formations which transgressed from opposite directions are those of late Black River and early Trenton ages which invaded the median portions of the continent alternately from the north and the south, as described on pages 367 to 371. Similarly alternating invasions occurred during the Richmondian and the Niagaran and probably also during the late Devonian. The bearing on this principle of the interfingering Black River and Trenton formations referred to here is thought to be so obvious that further discussion is unnecessary. It being established that the formations overlap as described, probably none will question the infer-

ence drawn therefrom that the maximum thickness of each of the formations invading from the north is older or younger, as the case may be, than the whole of its nearest southern contemporary.

Demonstration by Niagaran overlaps.—The Niagaran oscillations cover a longer time and the variously derived formations are but seldom brought into direct superposition. Surely, too, the depositional record of this stage in the continental basins is more than usually incomplete. The problems, therefore, are correspondingly more complex and the solutions in most instances too largely theoretical to be satisfactory. However, the Clinton part of the story as now understood seems reasonably convincing, while the sequence worked out for the upper half of the series is perhaps sufficiently plausible to deserve trial.

The oldest known Clinton is the Brassfield limestone or Rhinopora verrucosa zone—in other words, the "Ohio Clinton." This easily identified zone, though somewhat irregular in outcrop, is yet widely recognized in the Ohio Valley and western Tennessee. In Oklahoma it commonly forms the basal part of the Hunton formation; in Arkansas, where it has been seen at three localities in the Yellville quadrangle, it is provisionally mapped with the Saint Clair limestone. Logan and Hall studied it at Hamilton and other points in Ontario and placed it in the Clinton, but at Niagara Falls, where the same horizon is more arenaceous, authors have generally included it in the Medina. In the Appalachian Valley it seems to be confined to the Tennessee basin. In this it was observed in Elk Valley, White Oak Mountain, La Follette, and Rockwood, in Tennessee, and Lavender Mountain, Georgia. The fauna doubtless invaded from the Gulf of Mexico.

The Brassfield is succeeded—always abruptly and with evidence of hiatus—by various formations at different localities. At Niagara Falls and in the Tennessee basin later Clinton deposits rest on it, in Indiana and western Tennessee the Osgood limestone (equals Rochester shale) overlaps it, in Oklahoma any one of several much younger Silurian horizons may be in contact with it. Taking the Indiana succession—Brassfield and Osgood, both southern invasions—we would expect, as in the preceding Pamelia-Lowville case, at least one intermediate Atlantic invasion. On investigation this seems to be precisely what occurred, free communication with the Atlantic while the middle Clinton deposits were being laid down in New York and the western part of the Appalachian Valley as far south as northern Tennessee being as firmly established as fossil evidence can do it. These middle Clinton zones contain graptolites, a distinctive coral, peculiar bryozoa and brachiopods and several ostracods, all of types never seen in Silurian faunas that invaded from the Gulf of

Mexico. Beds of corresponding ages, moreover, are not seen to the west of the Allegheny basin, except (1) in south central Ohio and east central Kentucky, an area that was included in this Clinton sea, and (2) possibly in northern Arkansas. The Arkansas deposits thought to be of middle Clinton age are included in and commonly constitute the whole of the Saint Clair limestone.

The Saint Clair fauna as now understood is three-fold, the Brassfield at the base and a very different association at the top. The latter reminds in some respects of the Osgood, in others of presumably later Niagaran faunas at Chicago and in Sweden. So far it has been seen only at Marble, in eastern Oklahoma. Between these two faunas is another that has become, through the studies of H. S. Williams, Stuart Weller and Gilbert Van Ingen, the best known of the Saint Clair faunas. It contains some Brassfield species, but with these a greater number of forms that are either the same or closely allied to British and Bohemian Silurian species.

Strictly speaking, the term Saint Clair properly belongs only to the fauna and beds of this middle member. As we have seen, tilting and warping occurred between its time and that of the Brassfield so that the deposits of the latter were laid down in embayments of Ozarkia that did not lodge the second fauna. As to the upper fauna it is not seen in Arkansas; and the typical Saint Clair species have not been found in Oklahoma. I see no other way to account for these differences in geographic distribution than by assuming intermediate time breaks in which differential oscillation occurred.

The point of chief interest and significance in this connection is that the typical Saint Clair fauna is very different from all typical Clinton faunas; and no deposit is known in which intermingling of the two is even suggested. It is concluded, therefore, that if the typical Saint Clair is really of middle Clinton (Wolcott) age and not an intermediate stage between the Williamson and the Rochester of the New York section, then its sea must have remained wholly distinct from the typical middle Clinton sea which occupied the Appalachian and Allegheny basins. In the succeeding Rochester-Osgood age the Atlantic connections were closed and Gulf of Mexico waters captured areas previously invaded from the east.

As intimated the post-Clinton Niagaran oscillations are interpreted largely according to theory. My views, therefore, are correspondingly tentative. The only points on which I am inclined to insist are (1) that the dolomitic Niagaran deposits in Wisconsin were derived from waters invading from the north and that the more calcareous and shaly

sediments of Silurian age in western Tennessee, north Arkansas, Okla-

Suggested Sequence of Niagaran Deposits in North America

Western Tennessee, north Arkansas, and Oklahoma			Middle and northern Appalachian and Allegheny regions	Wisconsin
Cayugan		Decatur		
			McKenzie	
Niagaran	Chicago	Louisville		
				Guelph
		Bob and Beach rivers		
				Racine
		Dixon		
		Lego		Waukesha
		Waldron and Laurel		
				Mayville
	Clinton	Osgood and upper St. Clair	Rochester	
			Williamson	
		St. Clair (typical)	Wolcott	
			Sodus	
		Brassfield		? Iron Ridge ore bed

homa, Kentucky, and southern Indiana are southern in origin and invaded the continent from the Gulf of Mexico; (2) that either the whole

or the greater part of each of the Wisconsin Niagaran formations was deposited when the Gulf waters were excluded from areas in Tennessee and elsewhere in which their Silurian deposits are now accessible; (3) that the Lockport dolomite of New York is wholly of the age of the Guelph and represents an eastward transgression of this Arctic sea from Wisconsin comparable to the much earlier Prosser (early Trenton) transgression described on page 369; (4) that the hiatus between the Rochester and Lockport in New York represents the Waukesha and Racine formations, and probably also the Mayville, in Wisconsin, and the formations in Tennessee and Indiana beginning with the Laurel and ending with the Beech River; and (5) that with the possible exception of the Mayville, which may be late Clinton, and the Iron Ridge ore bed, which is probably of the age of the Brassfield, the Clinton group is not represented in Wisconsin. Except those covered by these conclusions and those placed in the Cayugan, the positions assigned in the following table of Silurian formations in America generally referred to the Niagaran are entirely hypothetical and provisional.

It is to be noted that the formations making up the sequence are arranged in three columns, the first giving the southern formations as developed in western Tennessee, north Arkansas, and Oklahoma, the second those in the Appalachian and Allegheny basins having Atlantic connections and third, those in Wisconsin which are regarded as originating in the north.

(18) Correlation based on inferred rhythmic shifting of the area of maximum deposition in successive ages.—It is an interesting and significant fact that the location of the area in which occurred the maximum deposition referred to a given period, epoch or age, or to which the deposits of the several ages are confined, varied from time to time. The shifting of the area, especially in the early periods, seems to be in accordance with some definite plan of oscillation and structural deformation. The reconstruction of this plan is of course no easy matter, and no determined effort to do so will be made at the present time. Our immediate concern relates to the fact that the presence or absence and the areal extent of many and perhaps most of the stratigraphic units recognized in the Appalachian Valley is largely determined by the altitude or degree of development of certain permanent lines of weakness, and of consequent positive tendencies, that run parallel with the general strike of the valley and of others that cross the strike. The location of these anticlinal axes along which stratigraphic overlaps commonly occur is shown in a generalized and imperfect manner on figure 1, page 293.

Subdivision of the Appalachian and Allegheny geosynclines by transverse axes.—According to information now in hand, the Appalachian Valley trough and the adjacent Allegheny basin between southern New York and central Alabama are each divisible into five parts by four subparallel and relatively unstable transverse axes. The most northerly of these broad axes passes in a northwesterly direction across the valley between Chambersburg and Lebanon, Pennsylvania, toward Niagara Falls. For present purposes it may be called the Harrisburg axis. The next to the south intersects the valley of Virginia between Staunton and Harrisonburg. The third or Wytheville axis passes across southwestern Virginia and may be a continuation of the Wabash axis of Indiana. The fourth axis crosses the Appalachian Valley in a northerly direction through the belt lying between Rome, Georgia, and Gadsden, Alabama, and presumably continues in a general northwesterly direction to the Nashville dome and thence on to southeastern Missouri. For convenience in reference the depressed areas separated by these axes may be named as follows: The *northeastern Pennsylvania basin* to the north and the *Maryland basin* to the south of the Harrisburg axis, the *central Virginia basin* to the north and the *Tennessee basin* to the south of the Wytheville axis, and the *Alabama basin* to the south of the northeastern Alabama or Gadsden axis.

These transverse axes do not cross the longitudinal troughs in continuous direct lines. On the contrary their course zigzags within the varying limits of a broad band so that the northern head of a bay in one trough may extend 50 miles or more beyond the latitude of the southern head of another bay in an adjacent trough. The band is wide enough and was always low enough so that regional tilting occasionally permitted overlap of edges of formations transgressing from opposite directions. Often the axis formed an efficient barrier in one trough and was much less effective or seems to have failed entirely in another. Most of the latter cases, however, are indicated by formations that are not contemporaneous. Sometimes again, a bay connected with waters occupying another trough in which the submergence extended across the transverse belt which, while limiting the submergence in the first, failed to do so in the second. Such a case seems to have been the Holston, which sea was limited in the Knoxville troughs on the north by the Wytheville axis but not in the troughs to the west of these. In one of the latter the sea apparently extended northward to some point in Virginia between Staunton and Fort Defiance.

As a rule the southwardly overlapping formations in the Allegheny troughs west of the Appalachian belt of overthrust faulting extend much

farther southward before pinching out than do those in the Appalachian Valley proper. These relations suggest the bare possibility that the Allegheny area slipped southward past the more highly folded Appalachian part of the continent. In Pennsylvania, for instance, the typical New York Trenton thins southwardly from Bellefonte, where it is still 600 feet thick and seems finally to pinch out altogether. The latter point, however, lies some 50 to 75 miles south of where this Trenton might be expected to die out if the Harrisburg axis continued in anything like a direct course. Similar conditions are observed in the vicinity of Cumberland Gap, where certain formations of the central Virginia basin extend equal distances southward beyond the line indicated by the Wytheville axis in southwestern Virginia. The Sneedville limestone (Cayugan) and the middle and late Devonian beds in Newman Ridge which are commonly, but erroneously, referred to the Chattanooga shale are the most important of these formations.

Barrier efficiency of the Harrisburg axis.—The Harrisburg axis caused thinning or complete extinction by overlap of many formations. Some of the latter lapped out in only one or two of the valley troughs and passed on northward to New York in one or more of the other troughs. Others, particularly those which are limited to the valley basins, failed completely to pass over it.

Of formations in northeastern Pennsylvania, southern New York, and northwestern New Jersey, the Ozarkian Allentown formation, the middle Chazy, which extends southwestward to near Hollidaysburg, Pennsylvania, the Normanskill shale, the Lehigh Valley cement rock, and probably the Oswego and Juniata sandstones are confined to the northeastern Pennsylvania basin. Lithologic peculiarities and partial restrictions, as the cutting out of the Cayugan, Helderbergian, and Ozarkian in Dauphin County, are noted in other Paleozoic deposits.

In the Maryland basin most of the Eopaleozoic formations exposed in the Cumberland Valley fail to pass over the Harrisburg axis. Referred to by name, these are the Tomstown limestone, the Waynesboro shale, and the Elbrook limestone of the Cambrian, the Conococheague of the Ozarkian, and the lower, middle and upper Stones River, the several divisions of the Chambersburg limestone, and a reddish Cincinnatian sandstone that is erroneously referred to the Juniata by Stose. The lower Cambrian quartzite, the Beekmantown, and the Martinsburg shale pass through to New York. West of North and Tuscarora Mountains the Copper Ridge chert, the lower and middle Stones River, the greater part of the Keyser, and the Greenbrier limestone do not extend north beyond the Maryland basin.

Formations limited by the Staunton barrier.—The Staunton or Fort Defiance axis prevented southward extension in the Appalachian Valley of the Elbrook limestone, the Conococheague formation, the Stones River, and the Chambersburg, all limestone formations of the Maryland basin. It prevented also northward extension of the Murat limestone, the Athens shale, and the Liberty Hall limestone, three of the valley formations in central Virginia. Whether it exerted any well marked effect on the distribution of later formations west of the Allegheny Front is unknown.

The Wytheville axis as a barrier.—The principal formations which failed to extend across the Wytheville axis are the following: The Stones River and the Liberty Hall lapping out from the north; the upper Cambrian formations, the Knox, the Holston, and the Tellico from the south in the eastern troughs of the Appalachian Valley proper; the middle divisions of the Clinton, the Sneedville, the Helderbergian, the middle and upper Devonian, late Tennessean and early Pottsvillian formations from the north; the Brassfield *Clinton*, the typical Chattanooga, and the Fort Payne from the south in the eastern part of the Allegheny basin. In the western troughs of the Appalachian Valley the upper Cambrian formations, the Copper Ridge chert, and the Murat Limestone part of the Holston extend northward from the Tennessee basin into the central Virginia basin. In the eastern—Athens—trough the Canadian Jonesboro limestone similarly extends across the Wytheville axis.

The Gadsden barrier.—The northeast Alabama axis vitally influenced the distribution of many Paleozoic formations. As noted on page 549, the Ozarkian has three formations in Alabama beneath and another, the Chepultepec, above the typical Knox that are not seen in Tennessee. The Alabama basin has also a thick Canadian limestone, the Frog Mountain *Oriskany* sandstone, the Tennessean Floyd shale, and considerable Pottsvillian deposits, all of which formations were cut off on the north by this axis. The Stones River limestones also have a development to the east of the Rome barrier that is much greater along the strike of the rocks than is seen to the north of the axis. Finally, the deposits of Black River age to the east of the Cahaba coal field, as seen in the vicinity of Pelham, Alabama, differ greatly in character and thickness of beds and in their faunas from beds of the same epoch in east Tennessee.

The list of formations developed in the Tennessee basin east of the Rome barrier and which do not extend into the central Alabama basin comprises the Lenoir limestone, the Holston marble, the Tellico sandstone, the Ottosee formation, and the Waverlyan Grainger formation along the foot of Chilhowee Mountain. It may be added that in places

on the dividing axis the Fort Payne rests on the Knox dolomite, but a considerable part of this hiatus is probably due to pre-Waverlyan erosion.

The transverse, northwest-southeast axes are believed to have extended across Appalachia to the sea. However, as time went on and the belt of folding migrated inland their natural tendency to form peninsular projections between broad embayments of the shore must have grown less. It is scarcely indicated by the present shoreline, but I venture to predict that the close study of the Mesozoic and Cenozoic deposits under the coastal plain now being carried on by Mr. T. Wayland Vaughn and associates will show that during these ages the tendency of the axes to form peninsulas was still well expressed.

Bowing of the Appalachian tract.—Finally, it is a significant fact that the two northwestwardly bowed parts of the Appalachian Valley tract—these parts falling in the Maryland basin on the north and the Tennessee basin on the south—contain by far the greatest thicknesses of Eopaleozoic rocks. They are of great thickness also in and northeastward from the Champlain Valley, where the Appalachian strike is similarly bowed. And in central Alabama, close to the Cretaceous border, where the strike also turns somewhat westward, the aggregate thickness of Eopaleozoic deposits is much superior to their development in the three southeastwardly bowed parts of the Appalachian Valley. On the other hand, the latter parts are backed immediately to the west of the valley tract by enormous thicknesses of Devonian and Pennsylvanian deposits.

This distinct distribution of the early and late Paleozoic deposits is believed to be the originating cause of the sinuous trend of the Appalachian Valley. The cause is really twofold. In the first place, the Eopaleozoic deposits consist largely of heavy bedded limestones; hence of material that is of more than average competence in the transmission of pressure. In the second place, these competent beds attain their greatest development in areas lying between other areas in which the Eopaleozoic deposits are not only thinner, but in which the Devonian and Pennsylvanian deposits in the Allegheny basins behind them are thickest. The latter, therefore, are not only capable of offering extraordinary resistance, but, because of the weak development of the older formations in the valley tract immediately in front of them, the westward transmission of pressure was here also less. In these eastwardly bowed portions by far the most of the contraction of the Appalachian tract was by overthrusting. The valley proper in such places is narrower than usual, being in fact entirely concealed in the Hudson Valley. In the westwardly bowed portions, on the contrary, the contraction was more distributed and a con-

siderable part transmitted by folding to adjacent portions of the Allegheny region.

Application of the principle.—Applying the principle of rhythmic shifting of the area of maximum deposition to systems in the Appalachian Valley, it appears that the area in which deposition continued longest was in the Tennessee basin during the Cambrian, in the central Alabama basin during the Ozarkian, in central and northern Pennsylvania during the Canadian, in east Tennessee again during the Ordovician, in the Maryland basin during the Silurian, in the northern Pennsylvania basin during the Devonian, in the central Virginia basin during the Waverlyan, and in the central Virginia and Alabama basins during the Tennessean and Pennsylvanian systems.

Applied to parts of systems in which considerable oscillation occurred, we find that during the Ozarkian period deposition in the Appalachian basins was at first confined to central Alabama troughs. Next the area of deposition was shifted to the Maryland and northeastern Pennsylvania basins, where the Conococheague and the Allentown formations were laid down. This was followed by the typical Knox, which, though strongly represented in Alabama, attained its maximum development in Tennessee. Northwardly the Copper Ridge divisions of the Knox extends to Roaring Spring, Pennsylvania, where it pinches out, presumably by overlap. Late middle Ozarkian, represented by the Chepultepec, is confined in the valley proper to the Alabama basin, but it must have extended northwardly in the Allegheny basins, since the fauna is recognized in Pennsylvania and New York. In the closing Jefferson City stage of the period none of the Appalachian basins seems to have been submerged.

Shifting of Ordovician seas.—North-south oscillations in the valley occurred very frequently during the Ordovician. Indeed, with the possible exception of the Silurian, sea-shifting seems to have attained its maximum on the American continent in this period. However, the oscillations were more gentle and the results more varied than in the Ozarkian. Space is lacking to point out the minor shiftings. Besides, most of them affected the basins of the Appalachian region in east-west directions and many of these have been referred to on other pages of this work. (See pages 321 to 328 and 544 to 557.) For present purpose, then, it will suffice to add a few words concerning the distribution of the larger subdivisions of the system.

During the Stones River epoch the volume of sediments and the time consumed in their deposition were not greatly different in the Alabama,

Tennessee, central Virginia, and the Maryland basins, providing, of course, that only the maximum development of the group in each basin is compared. There are troughs in each basin, especially in the east half of the valley between Staunton, Virginia, and Piedmont, Alabama, in which the Stones River is either entirely absent or but poorly developed. Southwest of Piedmont, as at Pelham, a stronger representation of the group is found. At and to the south of Pelham it is underlain by 500 feet to 1,000 feet of Canadian limestone, while over it are several hundred feet of more or less argillaceous limestone that reminds strongly of the upper members of the Chambersburg limestone in southern Pennsylvania. Incidentally it may be stated that the sequence at Pelham, Alabama, including the Stones River and the Canadian limestones, is in closer accord with the corresponding sequence in the Chambersburg-Strasburg belt (see page 321) than any section in the intermediate areas.

Following the Stones River, Blount (upper Chazyan), sedimentation set in and doubtless continued through a longer time in the Knoxville and Athens troughs in the Tennessee basin than anywhere else in the Appalachian Valley. This was succeeded by the Black River epoch, in which the area of maximum deposition was shifted northward to the Newman trough. Toward the close of the epoch, however, it was moved to the Chambersburg trough in southern Pennsylvania. In the Trenton epoch central Pennsylvania has perhaps as good a right to claim the area of maximum limestone deposition as east Tennessee. The best development observed in the latter State occurs on the west slope of Clinch Mountain, where it begins with the upper Moccasin. In Pennsylvania the equivalent of the Moccasin, which is older than the base of the Trenton at Trenton Falls, New York, is well developed at Reedsville. Here, however, the greater part of the succeeding Trenton consists of shale. The most complete post-Moccasin Trenton section observed to date is found at Bellefonte. Between the Reedsville and the Bellefonte sections the aggregate of Trenton limestone deposition in central Pennsylvania rises to something like 1,000 feet, which is little if any inferior to the aggregate for this epoch in east Tennessee.

In the beginning of the Cincinnatian stage—that is, in the Utica age—sedimentation took place in New York and probably also in the St. Lawrence Valley. Whether any part of the Appalachian Valley was submerged at this time can not be decided positively at this time. In my opinion, the presence of deposits of Utica age in this valley is highly probable only in the Maryland basin. Later Eden deposits, however, are confidently recognized throughout the length of the valley. They seem

to attain their maximum thickness in Clinch Mountain, Tennessee, though the development here does not greatly exceed that seen at McConnellsburg, Pennsylvania. Except that the closing Cincinnatian deposits in the valley proper are less generally distributed in the south and the deposits on the whole thinner, their distribution is much the same as that of the middle and late Eden shales. Extraordinary thicknesses were attained by the late Ordovician Oswego (Bald Eagle) and Juniata sandstones in central Pennsylvania.

Sea-shifting largely due to localized surface warping and torsion.—While continental tilting may be partly responsible for the sea-migrations cited in illustration of this principle, the chief cause no doubt lies in more localized surface warping. This is shown by the described shifting of the point of maximum continuity of submergence and deposition from one to another of the five Appalachian basins. Also by occasional emergence of the median troughs of a basin, while the troughs on either side are subjected to submergence. This condition is indicated by the middle Stones River-Lenoir line in the table facing page 545. The same table brings out also the opposite condition of median submergence and marginal emergence which prevailed during the Holston.

Still another phase of warping is shown in the Appalachian Valley. This suggests torsion of the valley tract, so that the point of greatest deposition moved eastward in one basin while westward shifting was going on in another. For instance, Stones River deposits are often partly and sometimes wholly absent in the eastern and middle troughs of the valley in the central Virginia and Tennessee basins and along the Rome barrier in the Alabama basin. So far as known, they are absent also in both the middle and eastern troughs in the northeastern Pennsylvania basin. On the other hand, the Stones River is fully developed in the middle and eastern troughs—that is, in the troughs to the east of the Rome barrier, in the Maryland basin toward the north, and in the Alabama basin at the south.

Almost directly opposite torsion of the valley tract had occurred when the next succeeding deposit, the Holston, was laid down. At this time the Tennessee and west central Virginia basins were largely submerged and slightly tilted eastward, while emergence and westward tilt prevailed in the Alabama basin and in the Maryland basin. As described on page 325, sedimentation at this time occurred in the Mercersburg belts of the Maryland basin and not in the Chambersburg trough.

Torsion is clearly exhibited also by the Oriskany and probably by other formations in the Appalachian Valley, but details remain to be worked out. Indeed, stratigraphers should class these movements among the

fortunate happenings, since it is to them we owe the fact that formations which are confined to distinct troughs in one basin are brought into superposition in another basin. Examples of this kind are cited under principle 6.

(19) Atlantic invasions occasionally superseded without break by Gulf of Mexico invasions.—Submergence of continental basins beginning with an Atlantic invasion occasionally passed without apparent break into a stage in which Gulf of Mexico invasion prevailed and in which the Atlantic connections were reduced, and finally closed. This condition seems to have been brought about by simple tilting, without decided warping of the area concerned. That it obtained is determined by local absence of a stratigraphic break between a fauna of the Atlantic type and a succeeding fauna of the Gulf facies. Closure of Atlantic connections was sometimes preceded by intermingling of faunas in the Appalachian troughs. The proposition may be illustrated by three examples as follows:

The stratigraphic relations of the Lowville to the underlying Ottosee formation in east Tennessee, partly described on page 550, indicates that the Atlantic tilt which prevailed in this region during the deposition of the Ottosee was gradually diminished during this age and the Atlantic communication finally closed by emergence about the time that Lowville sedimentation began in Hancock and Hawkins counties. In the section at Bulls Gap, in Bays Mountain, no break was observed in the Ottosee-Moccasin (Bays sandstone) sequence, and as the series between the base of the Ottosee and the base of the Moccasin is very thick here (at least 1,600 feet) it is not improbable that sedimentation continued uninterruptedly at this locality to and possibly through the Lowville age. However, to the west of Bays Mountain, which is in the Athens trough, the sedimentary process was clearly broken between the thinner Ottosee representatives and the succeeding Lowville (see page 557).

The second example is offered by the shales of the Eden group. Probably all will agree that the true Utica (the "Utica" shales of geologic literature range in age from the pre-Mohawkian Normanskill to the post-Trenton facies here referred to) had Atlantic connections. One of these seems to have been by way of the Saint Lawrence, another in the region of Chesapeake Bay. This belief is based primarily on fossil evidence. The Atlantic waters of the time extended westward as far as Cincinnati. If Gulf of Mexico waters also invaded the Ohioan province during a portion of this age, as seems probable, they were confined in the Ohio Valley to the west of the Carter axis and farther south to the west of the Cincinnati axis. The new post-Catheys Gratz shale, found in the lower part of the valley of Kentucky River and on the north flank of the Cincinnati dome, is provisionally determined as early Utica in age.

With the close of the Utica age of the Eden epoch the Atlantic connections were either partly or wholly closed or the marine currents which had previously swept through them were diverted. At any rate, the succeeding middle Eden fauna which lived in the now greatly expanded sea is almost entirely southern in origin. That limited communication with the Atlantic was maintained for some time after the Utica proper, or was reestablished in a brief subsequent time, is suggested by the middle Eden invasion of *Triarthrus*, mentioned on page 296. Before the close of the Eden, however, the fauna became so purely southern in type that direct connection between the Appalachian troughs and the Atlantic seems out of the question. The tilt of southeastern North America toward the northern Atlantic which prevailed during the Utica was thus reversed in direction, the resulting late Eden attitude of the affected areas with respect to sealevel being, furthermore, in essential respects much like that which prevailed in the late Trenton ages.

The differential oscillations which occurred during the course of the Clinton epoch make a case having much in common with the preceding Eden example. The essential features of the Clinton movements are suggested in the discussion of the Silurian sequence on page 558. Briefly restated in a manner suited to the present purpose, they are as follows: At the beginning of Clinton time the Brassfield sea invaded the Ohioan province by way of the Mississippi embayment to the vicinity of Hamilton, Ontario. After an interval, however, the succeeding pre-Rochester Clinton faunas invaded the Appalachian and Allegheny basins from the east. Reversal of tilt again took place during the Rochester, but on this occasion it seems to have been accomplished without complete interruption of sedimentation in the Appalachian Valley. In fact, there is an intermingling of Atlantic and Gulf migrants in the Rochester part of the Clinton in Pennsylvania and Maryland that is quite absent in the fauna of the Osgood limestone, the southern representative of the Rochester. Whether the indicated Atlantic connection was maintained to the close of the Rochester age has not been determined. However, it is not to be doubted that complete emergence of the Atlantic border set in directly after.

Similarly alternating Gulf of Mexico and Atlantic invasions are suggested by the distribution of the Onondaga, Marcellus, and Hamilton faunas and deposits in southeastern North America. Perhaps these are no less good illustrations of this principle, but in the absence of definite knowledge respecting the structural relations of the beds I hesitate to say that the movements in these cases were consummated without intervening emergence.

(20) Regarding oceanic connections of continental seas.—Discontinuous beds, lithically alike or unlike, but of the same period, stage, or epoch, which lap out from opposite directions on the flanks of a structural barrier and which contain faunas differing decidedly from each other in geographic origin and derivation, such beds must have had independent communications with distinct oceanic basins and, though appearing to hold similar stratigraphic positions, are likely to be of different ages. The matter of disparity in age in such cases has been sufficiently treated in discussing principles 6, 15, 17, and 18. As to the independent oceanic connections, these, especially in the case of Paleozoic formations, can in but few instances be positively demonstrated. As a rule, this is for the reason that the depositional record in the connecting straits or inlets has been eroded away or because it is now too deeply buried to be accessible. Under the circumstances it is only by reasonable inference, based chiefly on faunal data, that we are justified in asserting their former existence. The exceptions are the Gulf of Mexico and Arctic invasions of the Mississippi Valley. Of these the former thicken southwardly and pass under later deposits filling the Mississippi embayment, while the original extent of the latter is indicated by occasional remnants scattered over the northern lands to the present shores of the Arctic Sea.

Appalachian seas with Atlantic connections.—In the following endeavor to establish the proposition in cases wherein the connecting links have been buried or removed the discussion is confined to formations in the Appalachian Valley believed to have been laid down in Atlantic waters. Beginning with the oldest, these are the lower and middle Cambrian formations, the Levis shale, and the lower, middle, and upper Chazy and the Normanskill shale in the north, the Lenoir limestone, the Holston limestone, the Athens shale, the Tellico sandstone, and the Ottosee formation in the central Virginia and Tennessee basins, the middle and upper divisions of the Chambersburg limestone in the Maryland basin and equivalent beds in Alabama, the Trenton part of the Martinsburg shale, the Utica shale, the greater part of the Clinton, the Cayugan, and Helderbergian formations, the Oriskany, the Marcellus, and the Genesee shales, and parts, if not the whole, of the Portage and Chemung. All of the remaining Appalachian marine formations, except parts of the Grainger (Waverlyan), are regarded as deposited in waters invading from the south or in rare instances from the north.

As stated, the discrimination of the Atlantic seas from those that invaded from other sides of the continent is based primarily on faunal evidence. However, owing to the complicated structure of the area—its folds, overthrust faults, and irregular surface dissection—and in the

absence, even, of remnants of the presumable depositional record that formerly linked the valley rocks with the Atlantic basin, no other criteria are nearly so competent as the entombed faunas in deciding the questions at issue. Finding, as we usually do in the mentioned formations, that their faunas are limited on the west and south by some structural break or barrier, and if these faunas are of the facies that after long experience we have come to associate with the Atlantic province, no other explanation of their presence in an Appalachian sea than direct westward transgression of the Atlantic shoreline through depressions in the intermediate marginal land of the continent seems admissible.

Further, if exactly corresponding deposits are entirely absent or at least unknown in a considerable strip comprising the Cincinnati geanticline and extending from the Cretaceous border on the south to the pre-Cambrian areas in northwestern Ontario on the north, a condition that is quite true of all the mentioned formations, then their recognition as Atlantic deposits becomes almost unassailable. The absence of synchronous deposits in this intervening strip would otherwise be explainable only on the assumption of removal subsequent to deposition or of prohibition of sedimentation by current efficiency. Both of these contingencies, however, are impossible, as regards the Ordovician, Silurian, and Devonian formations which come to the surface in this crucial strip, because of their progressive overlap structure; and they are rendered highly improbable in the case of the inaccessible horizons by logical deduction from the demonstrated inefficiency of erosion processes in the interior negative areas of the continent during pre-Pennsylvanian ages (see pages 311 to 313).

Finally, direct Atlantic connection is proved for most of the Appalachian formations mentioned in a preceding paragraph by the fact that they are confined to certain basins, and within these to certain troughs in the eastern and middle parts of the valley tract. Their faunas being entirely absent in the stratigraphic sequence of the remaining western part, it is obviously impossible that they could have migrated from the west or southwest. Hence they must have come in from the east.

Depositional evidence of postulated Atlantic connections now almost entirely removed.—Bringing these faunas in by direct routes from the Atlantic has but one apparent drawback, namely, the general absence of connecting deposits. But, after all, is this objection really serious? I think not. We have but to remember that these connections were across a marginal tract of the continent which all geologists agree was frequently affected by orogenic movements, and perhaps as often base-leveled. The present surface of Appalachia therefore doubtless exposes

rocks that in early Paleozoic ages were deeply buried; and presumably much the same was true of the marginal strip before it was covered by the mantle of Mesozoic and Cenozoic rocks. In consequence of repeated elevation and erosion the Paleozoic marine deposits, which were here and there laid down on the broad and then unstable surface of Appalachia, were rather generally removed. Perhaps, indeed, the present remnants of these deposits, as, for instance, the Ordovician slates on the Virginia Piedmont, owe their preservation largely to burial beneath overthrust masses which, following subsequent general elevation and westward migration of the belt of folding (see pages 435 to 442), were later removed by erosion so as to again expose the crushed slates.

Assuming (1) that Appalachia was at one time traversed by longitudinal and transverse folds similar to those indicated in the Appalachian Valley and (2) that in their essential features crustal folds are permanent structures, it follows that the arched areas were less likely to retain the occasional sediments than the downwarped areas. Moreover, the low parts of the anticlinal ridges which were submerged at such times probably formed connecting straits in which deposition must have been limited and possibly prohibited by current efficiency. Hence it is only in the old basins that any of the depositional record of the Atlantic connections of Appalachian Valley formations could possibly be preserved; and if there is any truth in the suggested hypothesis of inland migration of the belt of active folding, such remnants must be very rare. According to this hypothesis the belt of active folding began on the eastern border of the land and migrated farther and farther westward across Appalachia until some age in the Mesozoic era, since which time it has ridden as a whole without folding on deep-seated sheer planes. Rising thus as on an inclined plane, the surface of Appalachia, especially over its western half, has suffered long continued and often vigorous degradation. That the whole surface of this old land-mass has otherwise remained relatively stable since the transgressing belt of folding reached its western margin is shown by the slight deformation of the marine deposits laid on it during and after the Triassic. Differential tilting, gentle warping, and normal faulting continued, but folding ceased long ago.

For the reasons given it is not surprising that the depositional records of former Atlantic connections seem to have been almost obliterated. Still, though rare, there are at least two areas that retain fairly satisfactory remnants. One of these is in the Skunnemunk Mountain in southern New York and the adjacent Green Pond Mountain in New Jersey, which region contains Devonian deposits that suggest communication with the Atlantic and the Gulf of Mexico. Measured according to the strike

of the rocks, this area lies to the east of the usual limits of Devonian deposits in the Appalachian Valley troughs. The second area is in the Maryland basin, in which recognizable Cambrian and Ordovician deposits are found to the east of the Blue Ridge Mountains. Being as a rule badly crushed and more or less metamorphosed, the age relations of some of these rocks have always been somewhat doubtful. Fossils are very rare, but depending chiefly on physical criteria most of the sandstones and shales have been determined, no doubt correctly, as Cambrian. Recently Dr. R. S. Bassler found fossil evidence in the vicinity of Frederick, showing that at least a part of the limestone of that valley is referable to the Chambersburg limestone. Other parts suggest the Beekmantown of the Cumberland Valley. Some of the shales, too, are late Ordovician (Martinsburg) in age and not lower Cambrian, as had been supposed.

PART III—STRATIGRAPHIC TAXONOMY

Principles of Classification

GENERAL DISCUSSION

In the study of geology, the first essential, of course, is some competent and consistent method of classifying geologic events. Hitherto the paleontological method—that is, the advent and disappearance of fossil faunas and floras—has seemed to serve the purpose. In later years, however, accumulated observations have tended to show that fossil evidence is not so uniformly reliable as had been supposed; that not only single species, but associations of species sometimes occurred at lower horizons, at other times in younger beds, than the one to which they were credited in the standard section. At first it was thought that the interval between these varying occurrences expressed the time consumed in the gradual dispersal or migration of the organisms. Later when three or four appearances of the same fauna were found to occur at long intervals above each other in the same section, paleontologists began to speak of "shifting of faunas." This shifting was supposed to indicate involuntary migration from place to place within broad long-enduring continental seas in response to local change in environment. These observations naturally suggested distinct paleontologic and lithologic classifications and dual nomenclatures, which while checking each other in a general way were necessarily independent in detail.

All such suggestions are believed to be detrimental to the progress of stratigraphic science. There is only one method of classifying geologic history and that is the chronologic; and in the determination of the se-

quence of events and in drawing the time boundaries every criterion, be it physical or organic, should be employed. In correlation each set of criteria is found to have its limitations, and none is alone sufficient for the purpose of the taxonomist. Nor can we justly say that the paleontologic criteria are more important than the lithologic or diastrophic. The organic criteria doubtless are the most useful and in many cases are by themselves determinative where the physical evidence by itself may be quite incompetent. But as each method of correlation commonly requires the corroboration of the other criteria before a detailed final determination of the geologic history of a given area becomes possible, and as each fills its own place and carries out indispensable functions, they are all equally important. As a rule the several methods are logically supplementary. In studying a section the fossils give us the general position; the lithologic criteria checked by fossil evidence narrows the limit of possible error and the diastrophic criteria finally establish the exact location of the boundary sought.

Regarding such ideas as "shifting" and migration of faunas and floras, providing their conception contemplates time consumed in migration of sufficient duration to be definitely expressed in the geologic time scale, or if they are promulgated with a view to show the futility of endeavors to establish the contemporaneity of geographically separated occurrences, such views, it seems to me, are practically groundless. They do not sufficiently take into account the immensity of geological time. I tried to illustrate this with the case of a living shell, *Littorina littorea* (page 295), which has extended its range in the past fifty years so fast that at the same rate it might encircle the globe many times before the smallest stratigraphic unit now thought correlatable over wide areas could be laid down. The groundlessness of the fear that shifting of faunas may seriously affect the accuracy of correlation by fossils is all the more apparent if my belief that marine faunas were modified and developed only to a very limited extent in the continental seas is accepted. (See pages 495 to 501.) In my opinion, the evidence as a whole points very strongly to the conclusion that faunas passed from the oceanic basins into and about in the continental seas so rapidly that their appearance in New York and central Kentucky or Tennessee is to all intents and purposes of stratigraphic correlation practically simultaneous.

The presence or absence of a fauna in a given continental sea at a certain time is wholly dependent on whether or not its migration is opposed by physical obstacles. When conditions for expansion of range were favorable, then the fauna instantly took advantage of them; if they were not propitious, then the organisms either succumbed or they retreated to

regions where existence was still possible. In the shallow continental seas life conditions could never have continued unbrokenly favorable through long ages; hence the faunas which inhabited them required continual replenishment. And it is to be remembered that geological time was always long enough for the consummation of every such purpose. Also that the fossil record of these small breaks in the life history of the beds is rarely measurable stratigraphically.

The modification of species and faunas that originated and developed in the same oceanic basin was very slow. This is shown by comparison of successive invasions from a given oceanic basin. Even when we can prove by stratigraphic evidence that long ages intervened the change is often deceptively small. The Hamilton, the Spergen, and the Catheys-Fairview "recurrences" discussed in foregoing parts of this work are convincing illustrations. And there are many other instances of confusing similarity in general aspect of long separated faunal invasions. Compare, for example, the late Stones River (Lebanon and Carters) fauna with the Lowville fauna. These two appearances of the Gulf of Mexico fauna are in general very much alike, and except for the constant presence in each of a few well marked diagnostic species their discrimination would be a matter of grave difficulty. And yet, as shown on pages 554 to 557, the Lowville is sufficiently younger than the last of the Stones River to permit deposition of the Blount group, aggregating between 3,000 and 4,000 feet of limestone, shale, and sandstone in east Tennessee.

When a decided generic change is noted between two immediately superposed faunas it means one of three things. Often it signifies that a great stratigraphic hiatus lies between them. In other cases the two faunas invaded from different oceanic realms. In the remaining cases some diastrophic change occurred within an oceanic realm, in different parts of which two or more facies may have been developing simultaneously. In the first two conditions the causes are obviously sufficient to produce the noted effects. The last cases, however, are not so simple. In these we have no sure means of determining what actually took place. It may have been an extraordinary restriction of normal habitat, as when great emergence of the continental shelf occurred. Or it may be that some land barrier, perhaps an intercontinental connection, was submerged, permitting influx of types previously excluded. Again, a passage, as, for instance, that between the Caribbean Sea and the Gulf of Mexico, may have been closed at times when the Antilles were connected with the Floridian peninsula. Finally, an intercontinental land connection may have been temporarily established, as between eastern Canada and northern Europe, which would have favored shore migration that at other times

was impossible. Any of these possible conditions, if they occurred, as it is believed they did, must have had a decided effect on the composition of faunas that invaded the inland seas.

Considering the many possible conditions that are competent to cause breaks in the faunal record of local stratigraphic sequences, whose magnitude is in nowise proportionate to their respective time values, the varying import, hence the inadequacy, of fossil evidence as a primary factor in the construction of a detailed geological time scale is apparent. The only possible basis for this scale lies in the stratigraphic relations of the beds containing the fossils and in the movements which have occasioned the shifting of the seas in which the beds were laid down and in which the fossil organisms lived when conditions were favorable. The remains of the latter are endowed with taxonomic attributes only when their stratigraphic relations have been determined; and at that, except in a broad and generalized way, the application of the life sequence thus worked out is limited by provincial boundaries. A new sequence must be worked out for each of the other provinces.

The stratigraphic taxonomist, therefore, must be first and always a stratigrapher. But, so I may not be misunderstood, I shall add that a geologist can not be a self-competent stratigrapher unless he is equipped with a considerable working knowledge of fossils. It is not required of him to know that a certain guide fossil is a *Hebertella* and not a *Dinorthis,* or that the species which was formerly called *Orthothetes subplanus* is now referred to under the name *Schuchertella subplana.* Such changes are in systematic biology and have no vital effect on stratigraphic taxonomy. What he needs is the ability to discriminate closely between allied species and faunas and to recognize the individual forms and their associations when he sees them again.

Whatever the cause of the faunal change, be it great or small, local or general, it probably was occasioned by some crustal deformation, and movements of the lithosphere necessarily were accompanied by corresponding displacements of the strandline. It is therefore by the correlation of these displacements, which involves the use of all the criteria—the physical no less than the organic—that we finally establish the sequence of marine deposits and define the stratigraphic units, whose classification is the chief object of this work.

BASIS OF PROPOSED REVISION OF STRATIGRAPHIC TAXONOMY

Discussion of the factors.—The criteria and principles of correlation have been discussed at length in preceding parts. It will have been noted that in estimating the relative values of the several criteria and methods

those implying earth movements and resulting displacements of the strandline finally assumed the distinction of developing the basic principles. Though not treated in such order, the other factors have become more or less obviously secondary in their evolution, operation, and standing to the diastrophic criteria. The reason for this is that the other factors originated in diastrophic movements and their effectiveness is conditioned by them. These movements caused changes in environment, and these in turn influenced the evolution of organisms and occasioned physical phenomena which are reflected by variations in the character of the deposits. The basis of the proposed classification, therefore, is primarily diastrophic.

The displacements of the strandline indicated by close field study of the sedimentary rocks are really separate, and locally but occasional stages of a continuous process. The sea was ever either advancing or retreating from the surface of the positive parts of the lithosphere, the invasions of the continental basins, except most of those coming in from the north, being always slow and gradual, the evacuations relatively rapid and seemingly impulsive. At certain times the displacement was so great that the marine waters were entirely withdrawn from the continental basins, but in a much greater number of cases the withdrawals were provincial or even more local in extent. Again, by tilting of the land surfaces, be they of the size of continents or only subsidiary positive areas, one side was submerged while the opposite side remained emerged.

So far as the relative magnitude of these displacements can be determined it is utilized in determining the rank of the respective boundaries. But the fact that discontinuity of sedimentation—hence, presumably, emergence—is indicated at the same horizon in widely separated sections does not by itself establish a boundary of the first (era) and second (system) grades. Such importance may be positively ascribed to it only when it has been shown that the horizon is somewhere associated with evidence of unusual diastrophic activity. The best evidence of such activity is the presence of clastic deposits, which, of course, implies degradation following land elevation in contributing areas. But, according to the theory of inland migration of the belt of folding, deposition of clastics at such times in the Paleozoic seas may have been confined to areas now inaccessible and to such other areas in which their subsequent removal by erosion was favored. In the latter instances, therefore, the reputed high valuation of the boundary rests in part on inferred probabilities by virtue of which the paucity or absence of clastic deposits in accessible situations is explained. Two Eopaleozoic systemic boundaries are espe-

cially referred to here, namely, the first between the Cambrian and the Ozarkian, the second between the Ozarkian and the Canadian. The distinctness of these three systems probably would not be so confidently asserted were it not for the belief that the orogenic movements at these times were confined to belts so near the margins of the continent that detrital material could not be supplied to the inland basins in which the rocks of these periods are now exposed. Apparently for like reasons the Siluro-Devonian transition in America is similarly devoid of clastic deposits.

Cardinal principle of the new stratigraphy.—The point that should be continually borne in mind is that the accessible stratigraphic sequence, at whatever locality and however obscure the breaks, is always incomplete. The more complete the stratigraphic record the more numerous the hiatuses, the fewer the breaks the greater their average time values; and the relative conspicuity of the stratigraphic break is never a safe indication of its importance. A sandstone may be followed without intervention of other deposits by another sandstone, or it may be two shales or two limestones that are in such close contact that continuous deposition is suggested; and yet a great time break with emergence may often be proved to have separated them. (See pages 526 to 532.)

Neither is the relative volume of deposits nor their areal extent a safe criterion. Two or three periods may be locally represented in a few feet of sediments. This is really a common occurrence on the flanks of the Nashville dome, where the Silurian and Devonian are often represented by thin overlap wedges. On the flanks of the Ozark dome, indeed, not only the Silurian and Devonian but the Ordovician and Canadian systems as well are locally absent and never strongly represented. Here, then, four periods may be represented in a varying sequence of deposits aggregating but a few hundred feet in thickness. If these fragmentary records were all that was known of these systems, it would be very difficult if not impossible to prove their true significance in the time scale. Fortunately, each is represented elsewhere by thousands of feet of sediments. More fortunately still, we can prove by satisfactory evidence that the thin wedges represent only small parts—usually the upper part—of widely spreading formations of their respective periods, which happened to extend by overlap to accessible situations on these flanks from some other area in which a more complete record was laid down.

Of all the features of the new conception, the smallness of the continental seas and the frequency and rhythmic occurrence of the oscillations, which caused withdrawal and shifting of the seas from one basin

to another and thus interrupted the process of sedimentation, will perhaps seem to the average geologist the most difficult to grasp. But these together constitute the very backbone of the revision. Without them the distant correlations largely fall to the ground or remain indefinite and unsystematized as they have always been.

It is not claimed that the basic ideas are new. The revision merely applies them more generally than was heretofore contemplated. We have long recognized that some of the Paleozoic seas were small, that they occasionally shifted their boundaries and that there must be something akin to rhythm in the great deformative movements that were more or less clearly suggested in the stony record. But these phenomena were treated as exceptional and local and not as definitely connected with a general systematically developed diastrophic process. That the strandline moved in obedience to the gradual development of this process and registered its stages, and that it therefore offered a definite and easily applied basis for stratigraphic correlation and classification, was only partially acknowledged. Chamberlin and Salisbury recognized the importance of the factor in so far as the major divisions of the stratigraphic column are concerned, but the demonstration of its applicability to minor divisions no less than the major has been left to the present occasion.

Method of dividing geologic time and definiteness of time units.—In stratigraphic taxonomy the first essential is the selection of some method or principle determining when a geologic age has ended and a newer age begun. Obviously such a principle applies equally to all the divisions of the time scale, the larger divisions, up to periods and eras, being but combinations of the minor units. In other words, the base or top, as the case may be, of a terminal unit of a group, series, system, or era at the same time correspondingly delimits the division of higher rank of which it forms a part.

In practice the stratigraphic terms system, series, group, and formation are treated as respectively equivalent to the time terms period, epoch, stage, and age. In fact, however, there is a difference. The latter refer to parts that taken in serial order completely fill geologic time. The former, on the contrary, account for only so much of this time as is represented by sedimentation in places now accessible. New discoveries, however, may at any time necessitate intercalation of distinguishable and hitherto unknown stratigraphic units and corresponding revision of the time units. Moreover, some of the inaccessibly recorded parts are occasionally penetrated in deep wells, but with such relatively unimportant exceptions they are truly "lost intervals."

Under this conception a geological age or time unit of the lowest rank determinable by diastrophic movements may be defined as a definite span of time. Displacement of the strandline being accepted as the dominant criterion a geological age is regarded as having closed when the marine waters were largely or wholly withdrawn from one or more of the continental basins, the succeeding new age as having opened when the sea again began to advance in the same or in other basins. Accuracy in the delimitation of time divisions therefore depends solely on our ability to correlate exactly the stratigraphic breaks in neighboring and distant basins. First we must be able to decide that the stratigraphic hiatus in one case is, geologically speaking, small, in another great. Then we must be able to say just how much of the hiatus is elsewhere represented by deposit. Finally, we should know whether or not a stratigraphic break is discernible at the base of the most complete depositional record known of a given age. When all these factors have been determined then, and only then, will we have exhausted the possibilities in the way of exactitude in delineation of time units.

Although the subject, in so far as the Ordovician in America is concerned, is far from being exhausted, it is yet true that great progress in detailed correlation has been made in the classification of the rocks of this period. And what is possible in the Ordovician is certainly more readily achievable in the case of the more widely accessible and as a rule more highly fossiliferous younger systems. It is only the older systems, which are largely confined to disturbed areas and in which fossils are less generally distributed, that present greater difficulties.

Revision of methods as well as facts of stratigraphic classification.—It will have been observed that my revision affects the methods as well as the facts of stratigraphic correlation. By method, I mean the manner of determining what constitutes a geologic period or system, an epoch or series, or a stage or group, and, more particularly, how the boundaries of these time and stratigraphic divisions are to be drawn. Concisely stated, the method followed is to divide the stratigraphic sequence at the first plane beneath the introduction of a new fauna or beneath a marked faunal change that exhibits evidence of diastrophic movements. If the plane marks a great faunal break, providing the compared faunas invaded from the same oceanic basin, and especially when the plane corresponds also to a considerable change in the provincial boundaries that had prevailed during the greater part of the preceding period, then it seems to me it marks the beginning of a new system. It is on such grounds that the old Mississippian is divided into two systems—the

Waverlyan and the Tennessean—also, that the Eopaleozoic is divided into four systems instead of but two.

Why the Waverlyan and Tennessean are systems and not series.—A system is divided into series on similar grounds, only in these cases the breaks are commonly of a lower order and the change in provincial boundaries less extensive. We may illustrate the difference by comparing the relations of the Waverlyan to the Tennessean on the one hand and the interrelations of the series divisions of these two systems on the other. Thus, during the Waverlyan, the continental seas were developed in southeastern North America in three fairly well distinguished basins or faunal provinces. Each of these provinces, furthermore, is characterized by its own lithological sequence. At times, also, the seas shifted so that only two or perhaps but one of the basins was submerged. Named from their characteristic formations, the eastern basin, with its shales and sandstones, may be called the Cuyahoga basin; the middle area, with its shales and cherty limestones, may be called the Fort Payne basin; the western province, with shaly beds beneath and at the top and rather pure crystalline limestone in the middle, may be called the Burlington province.

It may be questioned whether all three of these basins contained marine waters at any one time during this period. I believe this occurred during the Chattanoogan and, to a considerable extent also, in the New Providence-Fern Glen-upper Cuyahoga age, and again in the Keokuk-Fort Payne-Logan-Grand Falls age. The point is not of vital importance here. It is enough to know that, as a rule, the Waverlyan seas occupied considerable parts of at least two of the basins, and that the greatest shifting during the period occurred at times marking the close of the series into which the system is divided. Thus, as shown in the Maverlyan correlation table, the Chattanoogan ends with its most widely distributed stage; the Kinderhookian is characterized by frequent oscillations and ends with its smallest (Chouteau) stage; the Osagian begins with the extensive Fern Glen stage, continues with the restricted Burlington stages, and ends with another eastward tilt, during which the Keokuk was deposited in Iowa and Illinois, the Grand Falls in Missouri and the cherty Fort Payne limestone in areas to the southeast of these States.

As indicated, the Waverlyan oscillations merely shifted the seas about within the area covered by the three basins. The movements consisted almost entirely of simple tilting of the area as a whole. The break between the Keokuk and the Warsaw stage of the succeeding Tennessean period, however, as described on page 588, is marked less by tilting than by warping of the surface. The Warsaw, and to a greater extent the

Spergen, disregarded the boundaries of the faunal and lithological provinces which prevailed during the Waverlyan and spread with surprising uniformity of expression from Missouri to Alabama and thence northeastward in the Allegheny basin to west Virginia and perhaps to Maryland. There was a change, also, in the northward extent of the seas, none of the Tennessean stages reaching as far in that direction as did certain Waverlyan formations. In short, a new set of conditions was introduced in southeastern North America with the Warsaw that thereafter prevailed—with minor oscillations and tilting—to the close of the Chesterian.

CONSISTENCY OF METHOD IN DRAWING STRATIGRAPHIC BOUNDARIES

Discussion.—The method of dividing geologic time has varied largely according to the information and individual opinions of authors. Doubtless this is as it should be, for it would be a sad condition indeed if the science of geology, with special reference to its taxonomic aspects, should ever become so crystallized and fossilized that any scheme of classification, however well it may satisfy contemporaneous knowledge, were accepted as final. Fixity in method is death to progress, and, to say the least, it is presumptuous to even hope that any one has said or ever will say the last word on a scientific subject.

But there is one feature of method that may be fixed without detriment to science, namely, consistency in application. Of course, the success of our endeavor to be consistent depends largely on the state of our information. To that extent therefore it is just as liable to failure as any other feature of method. But it fails only in details, which can be corrected from time to time. Consistency therefore is a fundamental factor that can stand whatever happens to the scheme temporarily adopted.

In the old classifications undue prominence and rank was given to the younger formations. This is because they cover wider areas, are more commonly accessible, and contain a larger number and more beautifully preserved fossils than the older formations. Their fossils also were more readily comparable with living organisms, while the relative strangeness of the Paleozoic species naturally delayed the full recognition of their geologic significance. Moreover, most of the large cities of Europe are situated on Cenozoic and Cretaceous deposits, a circumstance that obviously contributed to their early investigation. As for the Triassic and Jurassic, these like the overlying Cretaceous and Tertiary formations, are well developed and highly fossiliferous in the Alpine regions of Europe,

whose grandeur of scenery and general interest attracted many geologists. Naturally we make the most of that on which we are best informed; and obviously, too, relative accessibility and ease of determining the sequence of deposits are matters on which the state of our knowledge largely depends. Thus compared the contrast in relative stability of classification between the Cenozoic and Mesozoic rocks on the one hand and the Eopaleozoic formations on the other is sufficiently evident to make further comment unnecessary.

Geological ages—that is, the minor divisions of the time scale—being distinguished from preceding and succeeding ages by the reversal of the movement of the strandline it seems desirable, on the ground of consistency, that the same principle should govern in deciding the limits of the larger time divisions. In other words, that we should endeavor to draw the boundaries between stages, epochs, and periods at horizons indicating the greatest and most widely recognizable stratigraphic hiatus or the greatest shifting and change in pattern of seas in the comprising part of the column. In the case of periods it should be drawn with due regard to the matter of rhythm in the progress of geological processes. (See pages 398-403 and 599-607.) In the case of eras it should be at the most generally recognizable horizon of this kind occurring in the midst of beds that in composition and structure indicate activity of diastrophic processes of the highest grade.

Hitherto there has been no uniformity in method of drawing boundaries of time and stratigraphic divisions below the grade of eras. One author drew the base of stratigraphic divisions at horizons thought to represent the beginning of their typical physical and organic development; another began the new formation, group, series, or system at the first introduction of species or faunas, or at the base of beds that were thought to be introductory to conditions assumed on the ground of experience to be typical of the new age. The former method, which commonly includes that of classification by lithologic criteria and the often very differently resulting method of classification by percentage or dominance of characteristic fossils, was possibly justifiable under the old conception of large continental seas and continuous deposition through one period into the next. Under the newer conception of small continental seas and frequent interruption of sedimentation it was seen to lead to so many inconsistencies and errors in correlation and classification that it is now thought wholly indefensible. Its greatest source of error lies in the fact that it entirely ignores the diastrophic factor of geologic history when this factor is not clearly indicated by sharp changes

in the character of sediments or by the structural relations of the beds. At their best the hitherto prevailing methods of drawing stratigraphic boundaries often obscure general as well as local geologic history, because the facts relating to changes in sedimentation are not brought out in their proper relationship. In many such cases, referring more particularly to formations, the so-called "transition beds" have been referred to either the top of the lower or the base of the upper formation without considering the probability of a stratigraphic hiatus beneath them. If the transition beds happen to be initial deposits of the upper formation, but agree lithologically more closely with the underlying formation, to which therefore they have been referred, the geologically important break is ignored while a relatively insignificant boundary is recognized. Many instances of this kind might be cited. In the case of larger divisions it happens occasionally that the fauna of a certain formation consists almost entirely of species whose alliance, for instance, are strongly Silurian, while elsewhere a synchronous or even a younger fauna is dominated by species recalling only Ordovician types. According to the old method one would be referred to the Silurian, the other to the Ordovician. On similar grounds contemporaneous formations have been referred to different series or groups. Oftener, however, general similarity in faunas found in locally superposed formations, or in geographically separated formations, which on the ground of such similarity may have been correlated, has caused their reference to the same group or series when in fact they belong to distinct groups or series. Examples of all of these conditions have been discussed and the difficulties explained in preceding parts of this work. And many more are indicated on the correlation tables appearing farther on. At the risk of repetition a few may be cited here.

The line between the Cambrian and the Ordovician, in areas containing a considerable development of these broadly conceived systems, was either not drawn at all or it was placed variously by authors at one or another horizon in the great intervening thickness of beds that is sharply defined above and below, and in fact includes representatives of two intermediate systems. In the case of the Siluro-Ordovician boundary it was drawn in New York at the base of the Oswego sandstone, a formation that is undoubtedly older than the Richmondian in the Ohio and Mississippi valleys, where the latter deposits were included in the Ordovician. However, in both of these cases the error lay not so much in method as in correlation. The same may be said of the Devono-Waverlyan boundary, which was drawn higher in the scale in Tennessee and Kentucky

than in northern Ohio, Pennsylvania, and New York, because of misapprehension respecting the stratigraphic relations of the Chattanooga shale to the upper Devonian in New York.

Prevailing inconsistencies in method—Examples.—Real inconsistency in method is shown in the practice of referring the Helderbergian series to the base of the Devonian, whereas the Richmondian is placed at the top of the Ordovician. These two series hold precisely analogous positions in the diastrophic histories of their respective periods. According to the method here adopted, both represent introductory stages, the Helderbergian to the Devonian, the Richmondian to the Silurian. The Saint Peter sandstone, with the Everton and Joachim limestones, similarly constitute an introductory series to the Ordovician, while the Chattanoogan represents the opening epoch of the Waverlyan. To be consistent, therefore, if the Helderbergian is early Devonian, then the Saint Peter is early Ordovician, the Richmondian is Silurian, and the Chattanoogan should be Waverlyan.

Coming to formations that for either faunal or lithologic reasons have been referred to groups or series to which they do not strictly belong, the following instances are probably as good as any. In each case the more important stratigraphic break has been subordinated to one of less significance. The first of these concerns the mistaken reference of the Lowville by myself and others to the Stones River group, which, as may be seen in the correlation tables, comprises the lower half of the Chazyan and is separated from the Lowville by the upper Chazyan Blount group. Study of diastrophic movements, stratigraphic relations and faunas finally proved the intimate relationship of the Lowville to the Black River group of the Mohawkian series, of which it should henceforth constitute the basal part.

The oldest Richmondian formation, the Arnheim, offers the second illustration. This formation has been referred by authors to the top of the Maysville group, but the Arnheim represents a return of Gulf of Mexico waters after a long stage of emergence. That warping occurred during this intermediate stage is indicated by the difference in distribution of the Arnheim when compared with that of the preceding McMillan formation. The relatively long duration of the intervening emergence is shown by the appearance of new organic types and the important changes that occurred in derivatives of the preceding facies of the Ordovician gulf fauna.

The Warsaw is of Tennessean, not Waverlyan, age.—The third and fourth instances are seen in formations adjacent to the Waverlyan-Ten-

nessean boundary, which, on account of locally similar lithic characters, have been referred to either side of the line. This occurred sometimes through misinformation, but at other times by design. Thus the Warsaw formation, which, because of intervening warping, differs widely in distribution from the preceding Keokuk and doubtless is separated from that formation by a long emergent stage, has been occasionally placed beneath the line, though more commonly associated with the formations of the Meramec group. Keyes,[72] and more recently Weller,[73] refer the typical Warsaw to the Osagian on the alleged ground that the Warsaw is but the "superior portion of the Keokuk," and that sedimentation between these two is "apparently continuous." I can not stop to discuss this problem here except in a general manner. To begin with, I shall express the conviction that the Warsaw proper is everywhere separated from the Keokuk by a stratigraphic hiatus. I may add that Keyes and Weller's contrary belief, which was formerly shared by myself, arises chiefly from the unwarranted assumption that the Keokuk is practically coextensive with the Burlington horizons, and that these formations, together with the Warsaw, are frequently embraced in a single stratigraphic unit. Recent investigations tend to show—indeed, they have to a large extent established—that these three formations differ widely in geographic distribution, diastrophic history, and age.

The Burlington constitutes the principal part of the Osagian rocks in the Mississippi Valley north of Saint Louis. This formation is well, though not uniformly, developed also on the north, west, and south flanks of Ozarkia, but on the east flank—that is, in the valley south of Saint Louis—it is unknown save a small patch of lower Burlington on the Aux Vases River southwest of Sainte Genevieve. The Burlington, further, is very commonly, if not wholly, absent in southern Illinois, in central Kentucky, in central Tennessee, and in the southern Appalachian region. The Keokuk, on the other hand, is usually present in the latter areas, but seems to be wanting on the northwest side of Ozarkia. Further, while the Burlington seems to have stretched over the greater part of the western two-thirds of this dome, as is indicated by remnants preserved in old sink-holes, the Keokuk sea left much of this median area uncovered. Evidently broad northwest-southeast tilting of the Mississippi Valley occurred, the Burlington being almost confined to areas west of the Kankakee Saint Francis axis (see map, figure 1, page 293), while the Keokuk, though extending northward in the valley proper to Iowa, was chiefly

[72] C. R. Keyes: Missouri Geol. Survey, vol. 4, 1894, p. 69.
[73] Stuart Weller: Illinois State Geol. Survey, Bull. 6, 1907, p. 24; Journal Geology, vol. xvii, 1909, p. 276.

developed to the southeast of the axis. The movement was of a kind that occurred frequently in Paleozoic times between formations of the same group or series. Apparently it was accompanied by very little local warping.

The Warsaw, on the contrary, followed a period of considerable warping and presumably of long emergence. Though widely distributed, the deposits of Warsaw age are everywhere but local in extent. In the Mississippi Valley proper I have seen them in only four localities, namely, in the vicinity of Warsaw, Illinois; in the valley of Meramec River, to the west and south of Saint Louis; in the vicinity of Columbia, Illinois, and to the west of Sainte Genevieve, Missouri. Each of these localities is included in an old downwarp. On the flanks of Ozarkia, besides the two points on the east side already mentioned, I have seen early Meramecian deposits (included in, but overlying, the more typical Boone) at Carrolton and Gravette, in northwestern Arkansas, and in the Joplin district, at Springfield and Carthage, in Missouri (see also page 593). East of the Mississippi they have been observed in Hardin County, Illinois; near Princeton, Kentucky; at the top of the Harrodsburg limestone, near Bloomington, Illinois, and here and there in central Kentucky, in the Highland rim about middle Tennessee, and to the north of Huntsville, Alabama. Apparently the same zone is represented locally in the Allegheny basin as far north as Ronceverte, West Virginia. Throughout this wide distribution the occurrences seem to be patchy, indicating deposition in small depressions of a profusely warped floor. As a rule, these patches are overlapped by later Meramecian deposits; and it is of high taxonomic significance that both disregard the limits of preceding Osagian provinces. Apparently the Warsaw introduced a new epoch and period which differed in many respects from the preceding Keokuk stage, but was merely carried on to its full expression in the Spergen and Birdsville ages.

Under the circumstances, therefore, I must insist that to class the Warsaw with the Keokuk, instead of referring it to the base of the Meramecian, is to ignore an important diastrophic boundary that is moreover clearly indicated faunally and in every way of greater significance than the Warsaw-Spergen line.

The fourth instance concerns the occasional reference of cherty Spergen and Saint Louis limestone to the Fort Payne chert formation by stratigraphers unacquainted with fossils. This is, of course, merely an unintentional error in practice that no paleontologist would be likely to make.

The relations of the Sainte Genevieve to the Chesterian and Meramecian.—The fifth illustration, finally, is that of the Sainte Genevieve lime-

stone, which formation or group I place at the base of the Chesterian, while Keyes and Weller, in the publications already cited, refer it to the top of the Meramecian. Essentially the same considerations are involved as in the case of the Warsaw. Had Keyes and Weller observed the stratigraphic break between the Sainte Genevieve and the underlying Saint Louis limestone, they would probably have given less weight to the fact that both are limestones and more to the well marked faunal differences. Disregarding the Spergen element in the Sainte Genevieve fauna—which may well be done considering that it reappears in equal strength at least twice afterward—the remaining constituent, as I have shown elsewhere,[74] is decidedly Chesterian. Warping and consequent shifting of seas undoubtedly took place following the Saint Louis, so that the distribution of the Sainte Genevieve in the Mississippi and southern Appalachian valleys differs widely from that of the Saint Louis. In the Cumberland Plateau and the southern Appalachian region the Saint Louis is commonly absent and in some places, as near Huntsville, Alabama, the little that was deposited of it appears to have been locally eroded away. The Sainte Genevieve in this general region, therefore, rests rather generally directly on the Spergen.

As to the Cypress sandstone, which Keyes and Weller place at the base of the Chester, this seems to be a local lithological development confined to areas adjacent to the eastern shore of Ozarkia. It doubtless indicates local movement, but, despite close search, no evidence of such movement was detected to the southeast in the Monte Sana section, near Huntsville. Here no satisfactory evidence of a stratigraphic break was observed between the top of an 0-6-foot wedge of Saint Louis limestone and the top of unquestionable Tribune limestone. Almost the whole of this interval, comprising perhaps 150 feet of beds, consists of oolitic and crinoidal limestones, the upper third or so containing characteristic Tribune species, the lower third good Sainte Genevieve fossils. Between these two zones are some 45 feet of beds in which neither of these faunas was recog-

[74] Professional Paper, U. S. Geol. Survey, No. 36, 1905, p. 45: Analysis of the Ste. Genevieve fauna herein listed brings out the following facts: Out of a total of 75 species 8 are confined to and, so far as known, strictly diagnostic of the Ste. Genevieve; 35 species are found in the Spergen beneath and in the Tribune limestone above, while all told 58 species are common to the Ste. Genevieve and the Tribune. Further, 17 species of the 75 range from the Spergen through the St. Louis and Ste. Genevieve and, with one or two exceptions, on into middle and upper Chester beds. These long-ranged species therefore, much like the Spergen forms, are to be counted as Tennessean fossils and as having no bearing on the problem beyond the determination of the period. Finally, 26 middle Chester species appear for the first time in the Ste. Genevieve, while only 6, in part doubtfully identified species, come up from the St. Louis and are unknown above the Ste. Genevieve. At the best, then, the faunal alliances of the Ste. Genevieve may be expressed by the ratio of 26 for the Chesterian to 6 for the Meramecian.

nized. It is at least possible, if not probable, that this represents the Cypress sandstone of the Kentucky-Illinois fluorite district.

On the basis, then, of (1) the widely recognizable stratigraphic break between the Saint Louis and the Sainte Genevieve, (2) the intervening diastrophic movements which occasioned very considerable shifting of seas, and (3) the introduction of many species which are otherwise unknown beneath the Cypress, Tribune, or Birdsville, the Sainte Genevieve seems more naturally classified as basal Chesterian than as uppermost Meramecian.

The principle of introductory facies of faunas and deposits—Discussion and illustrations.—The relations of the Sainte Genevieve to the succeeding beds of the Chester series are essentially the same as those of the Warsaw to the Spergen. They are also like those of the Richmondian to the Niagaran and of the Helderbergian to the middle Devonian. More exactly, though, they are comparable with the relations of the Lowville to the middle and upper Black River Mohawkian formations and of the Keyser limestone to the succeeding members of the Helderbergian. In all of these cases the first named stratigraphic unit—at least its lower part—commonly resembles the next underlying deposits more than it does the overlying beds. Yet, if our classification is to be chronoligic and based on diastrophic principles in which neither the purely lithologic nor the paleontologic criteria are of paramount importance, these units should be referred to the younger and not the older group, series, or system, as the case may be. In each of the mentioned cases I have endeavored to associate and classify the formations in accord with the principle that, quoting from Weller (op. cit., page 290), "the time boundary between two geological ages (periods) should be marked by the time of maximum withdrawal of the sea or the subsequent readvance during which new sets of conditions were introduced." From this quotation, which most geologists will indorse, it is seen that we agree in principle and theory. Differences arise chiefly in practice, when principles are frequently forgotten and mere likeness of deposits and absence of conspicuous evidence of diastrophic breaks in sedimentation is likely to dominate conclusions. In the case of the Lowville-Stones River contact its importance and really great significance has been shown in a preceding part (see pages 553 to 557). The Cayugan-Helderbergian contact also is now conceded to be unconformable in all known exposures and the usual hiatus between the two is admitted to be of greater time value than had been supposed. The same, again, is to be said of the Maysville-Richmond contact. The structural evidence of the stratigraphic hiatus in all of these instances is surely quite as clear

as in the late Niagaran-Onondaga contact at Louisville, Kentucky, and at Newsom, Tennessee, and in the similar contacts of Silurian and Devonian beds at Buffalo and elsewhere in New York—illustrations cited by Schuchert and generally accepted by geologists as satisfactorily established cases of long but inconspicuously marked time breaks. Under the circumstances, especially since stratigraphers are now practically a unit in placing the Helderbergian at the base of the Devonian, it seems to me we should insist on consistent treatment of all such cases. In other words, if the Helderbergian is Devonian and the Lowville is the lower part of the Black River group, then the Richmondian is Silurian, the Keyser is Helderbergian, the Warsaw is Tennessean, and the Sainte Genevieve is early Chesterian.

In applying the principle of introductory deposits to parts of formations, particularly when the underlying formation is of clastic matter and the overlying of limestone, general practice has been far from consistent. As a rule, however, these inconsistencies have resulted through lack of data and information. With plenty of determinative fossils, a mistake of this kind is unlikely. Without good fossil evidence, positive determinations are often difficult, but it is seldom indeed that close study of the structural relations of the "passage" beds fails to solve the taxonomic problem.

It may be set down as a general proposition that when a break in sedimentation is indicated at the base of a clastic bed whose top grades, without evidence of interrupted submergence, slowly or rapidly into less clastic deposits, then the new formation or group should include the former as an initial deposit, even though it is lithically much more like the underlying formation than it is like the overlying sediments. The Kiefer sandstone in Maryland affords an excellent illustration. This sandstone has hitherto been referred to as the top member of the Clinton. On investigation it was established that the Kiefer is a locally developed deposit, that it passes without break into the overlying sandy shales of the McKenzie formation, and that it is bounded below by an unconformity which in places cuts out the Rochester member or formation of the Clinton group. The intervening hiatus is regarded as representing the upper or Chicago group of the Niagaran series. On these grounds, which are supplemented by good faunal evidence, the Kiefer sandstone is now classified as a local basal member or facies of the McKenzie formation.

The Hardin sandstone in west central Tennessee and the Sylamore sandstone in north Arkansas are similarly referred to the Chattanooga shale. These, however, are true basal deposits of a widely overlapping

formation, differing from the preceding case in that the age of the bed varies from place to place according to the stage of the transgression. The relation of the Tellico sandstone to the Ottosee shale is more like that of the Kiefer to the McKenzie, only in this case the lower introductory member is of sufficient thickness and areal extent to rank as a separate formation.

In applying the principle great caution is always to be observed in determining the presence or absence of a stratigraphic break at the top of the clastic bed. Thus the contact of the Saint Peter sandstone and the succeeding limestone in the upper Mississippi Valley often suggests gradation from the sandstone through shaly sandstone and calcareous shale to the limestone. In fact, however, there is an important hiatus at the top of the Saint Peter, and the apparent transition suggested by the overlying mixed material is occasioned solely by the sandy character of the redeposited regolith of preceding Saint Peter land areas. In this case, then, only the variable and mixed intermediate bed, and not the Saint Peter itself, is to be regarded as the introductory deposit of the overlapping limestone formation. The Oriskany-middle Devonian sequence in the Appalachian Valley and in New York exhibits precisely analogous conditions.

The first appearance of fossil species and faunas.—As a general conception the first introduction of organic types is regarded as marking the beginning and not the closing term of geologic ages. It is deemed a valid interpretation even when the general composition of a fauna which contains a considerable number of such types is greatly like some older facies. This opinion and consequent practice is based (1) on experience, which teaches that reappearances (survivals) of faunal facies are more common in stratigraphic history than are preexistences, and (2) on the fact that the sedimentary record was frequently broken by inaccessibly or poorly recorded intervals in which new things were evolved without complete extinction of the old. The essential truth of the conception is clearly proved by prevailing views respecting reappearances of faunas, whose discrimination depends on a relatively small number of diagnostic new forms by which each is distinguished from all the others and not on comparisons involving their more numerous associates.

Time was required to evolve these new forms, so that their first appearance in continental seas may as a rule be supposed to have followed an inaccessibly recorded period during which they came into being. Or it may be that they are migrants from some other province whose previous exclusion was due to some physical barrier; or, if they happen to be

pelagic forms, like the graptolites and *Styliolina*. their invasion of continental basins may have been prevented by the absence of current thoroughfares. In either of the latter cases we may justly infer not only that ill-recorded time intervened, but also that diastrophic movements occurred which opened the way for freer intermigration. The introduction of new types therefore is always of possibly high significance and generally worth searching inquiry. And from the standpoint of stratigraphic taxonomy it is always of greater significance than is the presence of surviving older species. The new things show that something has happened, and that the happening was unusual is clearly indicated also by the partial extinction of the preceding fauna.

As intimated, the validity of the principle is universally admitted in the case of proved faunal recurrences like those of the Spergen. In these 50 to 80 per cent of the total fauna may be recurrent. According to the old method of correlation by matching of faunas, formations having anything like such a percentage of species in common were classified as unquestionably homotaxial or contemporaneous. But in the case of the Spergen we know from positive stratigraphic relations that its fauna invaded the Mississippi province at several widely different times. In consequence the indexical value of this fauna has lost much of its exactness. Indeed, it is practically disregarded when it comes to detailed correlations, dependence being now placed on the really diagnostic species which accompanied each of its several invasions.

Early Tennessean beds included in the "Boone."—The principle being recognized in these proved cases, why should it not apply also in those other cases in which recurrence has not been established by stratigraphic criteria but is as yet indicated only by the introduction of new faunal elements? A case in point is the upper part of the Boone chert formation in southwestern Missouri. This formation, including the beds in question, has hitherto been thought to be the equivalent of the Burlington and Keokuk limestones of Iowa. So far as known, the development of the Boone in the Yellville, Arkansas, quadrangle, where I studied the section in 1902, seems quite in accord with the prevailing conception of the stratigraphic position of this formation.[75] Subsequently I had occasion to study the Boone at other localities in Arkansas and Missouri and found that as mapped by geologists it frequently embraced beds at the top that must be younger than the Keokuk.

These upper beds are well developed at Gravette, Arkansas, and to the north in the Joplin and Carthage districts of Missouri. They begin with

[75] Professional Paper U. S. Geol. Survey, No. 24, 1904, p. 101, and table facing p. 90.

the Short Creek oolite member of the Boone as defined by Smith and Siebenthal.[76] Study of the fossils of these upper Boone beds reveals the fact that while they include a considerable percentage of good Burlington and Keokuk species (*Productus magnus, Spirifer rostellatus, S. neglectus, Aviculopecten amplus,* and a few others) these are associated with nearly as many more that are elsewhere found only above the Keokuk. In other words, these beds, like the Warsaw at its typical locality, introduce a goodly number of Meramecian species, among them *Fenestella tenax, Polypora varsoviensis, Spirifer subcardiiformis, S. lateralis, Rhipidomella dubia, Eumetria marcyi,* and *E. verneuilana.* On the strength of this evidence, which is in full harmony with diastrophic criteria bearing on the same problem (see page 588), I propose to draw the Waverlyan-Tennessean boundary in southwestern Missouri at the base of the Short Creek oolite and to confine the Boone to the underlying limestones. Whether the Short Creek oolite and the overlying "Carthage limestone" are strictly correlatable with the Warsaw or whether they are somewhat older can not be decided with the data in hand.

Locus of faunal evolution and antecedent occurrences.—If we accept the theory that the fossil faunas of the continental basins were evolved almost entirely in the permanent oceanic basins and only invaded the inland seas when conditions were favorable (see pages 495 to 501), recurrence of faunas is readily explained. While most of the proved recurrences are subsequent to the one which may be said to be typical, because it has given the name by which each is known, as, for instance, the Hamilton, the Spergen, the Utica, and the Catheys, it is obvious enough that earlier invasions than the typical one may finally prove no less common. To a considerable extent these earlier appearances may suggest exceptions to the application of the principle that the introduction of new faunal elements is of high value in stratigraphic taxonomy. But, so far I can see, the danger is more apparent than real. So long as the occurrences are carefully checked with demonstrated and probable movements of the strandline we are safe from grave misconceptions. Besides, most of the antecedent invasions fall within the same period, and commonly within the same epoch, to which the typical occurrence is assigned. The chief and perhaps only exceptions are among the pelagic faunas, which as a rule were subjected to less strenuous variations in environment than the littorial faunas, and consequently changed more slowly.

[76] Joplin folio, No. 148, Atlas, U. S. Geol. Survey, 1907, pp. 2-5.

The black shale faunas, which are largely made up of pelagic species and are neither very common nor varied, may be expected to give the most trouble. Thus it required close comparison to prove that the Maquoketa Richmondian fauna is really much younger than the Utica fauna, or that the faunas of the early Trenton Martinsburg shale and of the middle Blount (pre-Lowville) Normanskill and Athens shales are much older. Of course, we know now how to distinguish them almost at a glance, but the belief that they are all of the same age—that is, Utica—prevailed for a long time. And we are not past the danger of confusing certain faunal facies of the Moorefield and Fayetteville shales, two Tennessean formations, with the Pottsvillian Caney shale fauna. The differences between the Genesee and Chattanoogan faunas, also, are not so clearly marked that one may distinguish them offhand. Finally, there is no satisfactory warrant for the claim that because certain black calcareous shales at the base of the Romney in Maryland and adjoining States contain pelagic or pseudopelagic Marcellus species like *Styliolina fissurella* and *Strophalosia truncata* the beds are of the Marcellus age. These species doubtless existed before and after the Marcellus, and in the case mentioned they, together with surviving Oriskany ostracods, may well have mingled with an Onondaga fauna in Maryland.

After all, we should treat these slowly modifying black shale faunas just as we do the recurrent littoral faunas—that is, we should estimate their respective time values according to the evidence of the few new forms that came in with each invasion, and which after well tried experience are set aside as reliable guide fossils. Frequently but one or two such species may serve our purpose very well, while general "matching" of full lists often leads to no definite result.

CLASSIFICATION BY DIASTROPHIC MOVEMENTS

Maximum, major, and minor movements.—All diastrophic movements and processes have ever been characterized by periods of activity alternating with periods of relative quiescence. Periodicity, then, is a fundamental factor of geologic history. Further, all diastrophic processes are rhythmic in operation and recurrence, because they are occasioned by the necessarily rhythmic action of terrestrial forces. In some the meter is long, in others relatively short; in some the effects are pronounced and relatively impulsive, in others gentle and gradual in development. Diastrophic movements thus offer a basis for classification.

There were *maximum movements* or "revolutions." These were marked by strong crustal deformation with decided horizontal move-

ment, especially toward the equator, by deepening of oceanic basins, and the formation of new geosynclines or the resubmergence of basins long unused; also by orogenic activity in marginal tracts of continents. Widespread emergence prevailed and the orogenic movements affected areas farther inland than did any preceding them. Erosive processes were especially active in the succeeding period or periods.

These maximum movements did not take place all at once, even in any particular area, but they were distributed through long periods in which diastrophic processes were more than usually active. Though long, the first, second, and fourth of these periods of activity were of much shorter duration than the periods of relative quiescence with which they alternated. The third seems to be more important than the others, the criteria on which extraordinary activity is postulated having begun earlier and continued longer. Stratigraphically, they are distinguished by extraordinary accumulations of detrital deposits in continental marine basins, and more particularly by the fact that apart from minor variations these deposits were laid down in areas farther inland from the borders of the continents than before, and perhaps since. The visible development of these criteria is modified by such theoretic considerations as the "inland migration of the belt of folding." (See discussion, pages 467 and 477.)

Four periods of maximum diastrophic activity are indicated. The first began in the closing stages of the Proterozoic and continued almost through the Cambrian. The second began toward the close of the Ordovician and continued through the early part of the Silurian. The third began late in the Devonian, continued to the close of the Jura-Trias, and attained its maximum at the close of the Tennesseean. The fourth marks the transition from the Cretaceous to the Tertiary. The great time intervals separating the culminating stages of these movements correspond essentially to the eras of the geologic time scale.

Then there were *major movements* which seem to have been chiefly of the nature of broad adjustments to strains engendered during the periods of maximum activity. They were marked by deepening of submarginal geosynclines, accentuation of already existing primary axes, and great sea withdrawals—all phenomena occasioned by landward suboceanic spreading. Commonly, these conditions were followed by a stage in which seaward continental creep prevailed, with profuse and extensive crustal warping and consequent great changes in pattern of continental seas. The major movements define systems, series, and to a large extent, also, the groups into which the stratified column is

divided. It is perhaps unnecessary to state that at certain times they are included in the operation of the maximum movements.

Finally, there were many *minor movements,* under which term we may refer to tilting of land masses, whether these involved the greater part of a continent or only some subordinate "positive" part of same, and to all movements that are relatively local in their effects on the strandline. Theoretically, these minor movements define geological formations or ages; also groups of formations which are distinguished on lithological grounds, but seem to have been deposited without break. They are commonly marked by retreat and subsequent advance of the sea without decided change in provincial boundaries, by deepening or emergence, as the case may be, of the subsidiary troughs of a geosyncline, and by local changes in the lithological facies of formations.

Obviously there is no sharp distinction between these three grades of movements. The minor movements vary to the point where they may justly be called major, and these again grade into those of the highest or maximum rank. Their taxonomic value, therefore, is correspondingly indefinite and peculiarly liable to personal differences in their estimation. The most generally admitted, if not the most convincing, part of the evidence from which diastrophic movements are inferred, namely, the clastic deposits, varies so greatly from place to place that wide difference of opinion respecting the taxonomic significance of the several occurrences is to be expected. The theory of inland migration of belts of active folding, also the proved small relief of the interior areas of the continents, helps greatly in explaining the paucity of detrital deposits at localities and times when much more might be expected. Fortunately, we have two other classes of evidence—(1) that showing stratigraphic overlaps, and (2) that showing the geographic derivation and distribution of fossil faunas and floras—that give no less convincing testimony in proving the frequency and varied kinds of movements. These two classes of evidence bear directly on the displacements of the strandline, and the variations in direction and extent of its transgressions give the surest proof of the instability of the lithosphere. Further, since the rhythmic periodicity of diastrophic processes is almost universally accepted as a fundamental fact in geologic science, these displacements logically become not only the ultimate but also the immediate natural basis of exact stratigraphic taxonomy.

Chamberlin and Salisbury's views on the natural basis of time division.—There are geologists who deny that the divisions of geologic time which are natural for one region are similarly natural for another re-

gion. But there is a rapidly growing class of geologists who believe that there is a natural system that, at least in its broader lines, is of general applicability. Chamberlin and Salisbury (Geology, vol. 3, 1906, pages 192-194) have expressed themselves very clearly on this matter. As their views are in essential accord with my own, I shall take the liberty to quote them:

"We believe that there is a natural basis of time division, that it is recorded dynamically in the profounder changes of the earth's history, and that its basis is world-wide in its applicability. It is expressed in interruptions of the course of the earth's history. It can hardly take account of all local details, and can not be applied with minuteness to all localities, since geological history is necessarily continuous. But even a continuous history has its times and seasons, and the pulsations of history are the natural basis for its divisions.

"In our view, the fundamental basis for geologic time divisions has its seat in the heart of the earth. Whenever the accumulated stresses within the body of the earth over match its effective rigidity, a readjustment takes place. The deformative movements begin, for reasons previously set forth, with a depression of the bottoms of the oceanic basins, by which their capacity is increased. The epicontinental waters are correspondingly withdrawn into them. The effect of this is practically universal, and all continents are affected in a similar way and simultaneously. This is the reason why the classification of one continent is also applicable, in its larger features, to another, though the configuration of each individual continent modifies the result of the change, so far as that continent is concerned.

. . . "In these deformative movements, therefore, there seems to us to be a universal, simultaneous, and fundamental basis for the subdivision of the earth's history. It is all the more effective and applicable, because it controls the progress of life, which furnishes the most available criteria for its application in detail to the varied rock formations in all quarters of the globe.

. . . "It is too early to affirm, dogmatically, the dominance in the history of the earth of great deformative movements, separated by long intervals of essential quiet, attended by (1) baseleveling, (2) sea-filling, (3) continental creep, and (4) sea transgression; but it requires little prophetic vision to see a probable demonstration of it in the near future. Subordinate to these grander features of historical progress, there are innumerable minor ones, some of which appear to be rhythmical and systematic, and some irregular and irreducible to order.

. . . "In applying a classification based on body deformation, some regard must be had to the fact that while sea withdrawal, as the result of increased capacity of the sea basins, is simultaneous the world over, continental deformations and crustal foldings are more local and less nearly synchronous, for there is no agency to combine and equalize their effects as in the case of the basins. Continental deformations must be employed in the classification with some latitude, and correlations based on them can not be expected to have an equally high order of exactness. Local advances and retreats of the sea due to local warpings must be eliminated or neglected, in a general classification, for the reason that they are local."

The only statements in the above quotation that I am inclined to take exception to are contained in the last paragraph. I hold, namely, that continental deformations and crustal foldings disturb the isostatic equilibrium of the earth in proportion to their vigor and extent. If the land is raised by folding or weighted in any other manner, such part tends to settle back; and if any continental basin is loaded with sediment, its synclinal structure is likely to be accentuated. All such adjustments, I maintain, must have some effect on the strandline. If one side of a land mass is folded, the capacity of adjacent sea basins must necessarily be increased and its waters withdrawn from that side of the land. On the opposite side, however, increased submergence is likely to occur. If a continental basin be deepened and submerged, it would necessarily cause sea withdrawal elsewhere. This phase of the subject has been discussed at some length in describing tilting of positive areas. (See pages 405 to 407 and 411 to 432.) The efficiency of our correlations in such cases depends entirely on our ability to match an emergent stage here with a submergent phase there. Correlations of distant occurrences are seldom easy, and these are especially difficult. But there are ways of doing them which, I believe, will finally lead to a degree of success scarcely hoped for now.

Rhythm in Recurrence of geological Phenomena

GENERAL DISCUSSION

The endeavor to bring all the systems, and so far as possible the minor groups, into at least approximate coordination is justified by the belief that we may thereby determine and express something of the rhythm that seems to regulate diastrophic movements. That these movements occur in rsponse to very definite laws none will deny; and that their operation in past geologic ages was not merely casual, but that they progressed with a regularity in which such factors as time and volume were sufficiently prominent to establish a measurable rhythm in the recurrence of similar conditions seems scarcely less reasonable.

Of course, as time went on conditions changed. This earth is very different from what it was at its beginning. But while our conception of its primitive form is based almost entirely on pure inference the problems that go no farther back than the oldest fossiliferous rocks are far more amenable to solution. Our inferences respecting the latter, according to which the surface of the earth has by progressive modification changed from an almost featureless even expanse to its present diversified aspect, are grounded on a great and rapidly growing stock of observed facts.

Further, while we may reasonably assume that the regular operation of the laws governing diastrophic movements was locally modified by adventitious circumstances, and also that the average rhythm in recurrence of similar conditions has been subject to gradual change resulting from increasing complexity of structure, it yet seems probable that these circumstances were relatively so trivial and the change so slow that it is impracticable, not to say impossible, to account for them in stratigraphic taxonomy. So far, then, as practical geology is concerned, such considerations may be ignored. Viewed from the standpoint of pure science, the mere fact that the idea of rhythm in crustal movements is recognized as worthy of consideration—or perhaps even as an important factor—in the construction of the geological time scale is of itself a sufficient concession to progress in method.

The importance of the idea of rhythm in the progress of geological events lies as yet chiefly in its promising possibilities. To a small extent these have been realized and incorporated in principles bearing on detailed correlations discussed on pages 543 to 546. The idea is also graphically illustrated in the table on page 544, which shows the rhythmic northwest-southeast shifting of the Ordovician sea in the valley troughs in east Tennessee. In a broader way rhythm is indicated by the apparently regular recurrence of great emergences and revolutions at the close of the eras and by the other important breaks that delimit the systems and series. It is suggested also in the geographic shifting of the continental seas. Something of the kind is brought out in the discussion of principle 18 on pages 561 to 569.

Rhythmic movements are indicated again by the division of each era into four systems and most of the systems into three coordinated series. When there are four series, as in the Ordovician, then both the opening (Saint Peter) and the closing (Cincinnatian) part of the time allotted to a period is represented by deposition in accessible situations. When there are three or but two coordinate series, then either the opening or the closing stage, corresponding respectively to the Saint Peter and the Cincinnatian, or both stages, are included in the intersystemic hiatus of the accessible sedimentary record. (See page 338 for further discussion of this phase of geologic rhythm.) In southeastern North America it is mainly the early parts of the period record that is thought to be inaccessible in the cases of the Ozarkian, the Canadian, and the Pennsylvanian, the latest parts in the Cambrian and the Silurian, and in varying degree both the early and late deposits in the Devonian, Waverlyan, and Tennessean. These views are reached by investigations similar to those illustrated on page 343. That diagram, however, refers only to oscilla-

tions of the median parts of the continent, whereas the present discussion refers to the continent as a whole. If the idea in general is well founded rhythm in vertical oscillation is indicated in both cases.

Accessible deposits of detrital material are common or predominant in the terminal divisions of eras. Movements at these times differed from those in other intersystemic intervals in that they affected or rather extended to areas farther inland than did those in the next two intersystemic intervals. Rhythm is thus again indicated by periodicity in abundance of clastic matter in marine deposits as follows:

Abundant and coarse clastic matter in the	*Less and usually finer matter in the*
Belt-Cambrian interval,	
	Ozarkian, Canadian, and early Ordovician,
late Ordovician and early Silurian,	
	late Silurian, Devonian, Waverlyan, and early Tennessean,
late Tennessean and Pennsylvanian,	
	Jura-Triassic, Comanchean, and early Cretaceous,
late Cretaceous and early Eogenic.	
	late Eogenic and ? Neogenic.

The differences were well marked in the Eopaleozoic and Neopaleozoic, but with the increasing dominance of emergent phases in the Mesozoic and Cenozoic (see page 341) the contrast diminished to the vanishing point.

DIASTROPHIC RHYTHM IN RELATION TO THE DURATION OF GEOLOGIC AGES

As the final illustration of rhythm in geological processes I shall cite a few facts and suggestions bearing on the duration of geologic periods, namely, rhythm is suggested by the apparent approximation in time value of deposits referred to each of the Paleozoic periods. Reduced to a limestone basis, the average aggregate thickness of accessible beds representing most of these periods is between 4,300 and 6,000 feet each (see page 398). The aggregate for the Silurian, Waverlyan, and Tennessean systems, so far as known, falls more or less beneath this estimate, but oscillation and emergence prevailed to such a degree in these periods that the determination of the complete sequence for each is very difficult. When the sequence shall have been worked out, it is expected that the aggregate thickness for the Silurian at least, and perhaps also for the Waverlyan, will be brought much nearer the average than are the present figures. The Cambrian and the Devonian, as developed in the Cordilleran basin, seem to exceed the average Paleozoic system in thickness. Regarding these it may be suggested that the record here approximataes in completeness that laid down within the continuously submerged oceanic basins.

Hence, it may be further suggested, that the full time value of a geological period—assuming that they are approximately equal in value—corresponds to something near that of 7,000 to 10,000 feet of limestone. In view of the known exceedingly uneven distribution of marine deposits in the continental basins, and knowing further that the sedimentary record in the accessible parts of these basins, however thick it may be, ever exhibits evidence of interruption and incompleteness, this suggestion certainly is not improbable. We know, for instance, that a clearly broken sequence of over 4,200 feet of Canadian limestone was laid down in central Pennsylvania, and that no rocks of this age are to be found in certain parts of the Appalachian Valley in Tennessee and Alabama. Here, on the contrary, we find a similarly broken sequence comprising thousands of feet of Ozarkian dolomites that are wholly unrepresented by deposits in those parts of central Pennsylvania in which the Canadian is best developed. And each of the breaks in the two sequences may, as was shown by the Stones River-Lowville contact, represent deposition of thick beds elsewhere. After such proof of oscillation and long continuance of emergent conditions in first one and then in another part of the same geosyncline, there surely is no just cause for surprise in the suggestion that uninterrupted deposition in each of these periods may somewhere have reached a total of 8,000 to 10,000 feet. The idea is not of immediate consequence, but seemed worthy of mention to show the possibilities in the way of future expansion of the geological column.

Rhythm in the order of occurrence, location, and extent of oscillations, causing submergences and emergences of continental areas, doubtless will later on be determinable. At present, however, little of this is shown by published paleogeographic maps. Probably their unpromising exhibit is due to the often highly composite, not to say heterogeneous, nature of most of the maps.

RECURRENCE OF GEOGRAPHIC PATTERNS

As will appear in succeeding descriptions, the Paleozoic systems are distinguished by movements similar in intensity and effectiveness to those described on page 582 in showing why the Waverlyan and the Tennessean are systems and not merely series. The results, so far as the shifting of the strandline is concerned, vary from time to time; but strikingly similar recurrences in geographic patterns are common. These are to be noted more especially on comparing invasions from the same oceanic basin in the same period and these again with stages in the second succeeding or preceding period. For instance, the Ozarkian geographic facies are to a large extent like those in the Ordovician and these again like certain

facies of the Devonian and the Tennessean. At any rate, the geographic patterns of southeastern North America in the stratigraphically most important ages of these periods have more features in common than appear on comparison with maps depicting geographic conditions in Canadian, Silurian, and Waverlyan ages.

Recurrence of geographic pattern is due to two causes, first, the rhythm in diastrophic processes, and, second, original local differences in specific gravity, because of which certain areas are characterized by prevalence of positive tendencies and others by negative tendencies. The positive areas formed the original anticlines against which geologic formations commonly lap out; the negative areas, on the contrary, are the synclinal basins in which marine deposition frequently took place.

Naturally, the distinctive characteristics of the positive and negative areas are developed to varying degrees, being strongly expressed in one case and perhaps but weakly in another. Besides, an area that is normally negative may be included in a broader area in which, taken as a whole, positive movements prevailed. Obviously the vertical movements of such an area must be purely relative, its attitude with respect to sealevel being dominated by the emergent tendencies of the region of which it forms a part. Submergence of such an area of ill-recorded negative tendencies could occur only at times of unusual subsidence. On the other hand, relatively positive areas, as for instance submarine ridges and plateaus, may at times be dragged beneath sealevel by the dominantly negative tendencies of the general area of which they form subordinate parts. It seems no more improbable, therefore, that intercontinental connections frequently rose out of the area of the present oceans, than that there are now and ever have been relatively low places or valleys on the emerged parts of the lithosphere.

But aside from these modifications, which do not affect the idea seriously, the prevalence of positive movements in one region and of negative displacements in another has tended in corresponding degree to permanence in distribution of land and water over the face of the earth. Granting the principle of essential permanence of earth features, are we not justified in hoping that stratigraphic correlation and classification, and paleogeography as well, may finally become exact sciences?

RECURRENCE OF PERIODS OF WARPING

Pages 338 to 341 are devoted to a brief discussion of a phase of the diastrophic process that is not yet fully understood. It was observed, namely, that the accessible depositional record of certain periods began with extraordinarily extensive submergences whose geographic pattern,

moreover, resembles submergences of the preceding period more than those next succeeding. This was explained on the supposition that following the continental emergence, which prevailed for a longer or shorter time between each of the successive periods, continental creep caused general and relatively even lowering of the median parts of the continent. Occasionally, this median subsidence proceeds to the stage of submergence, resulting in a distribution of deposits that recalls preceding ages in extent and areas covered. The idea is illustrated by the early Canadian Stonehenge limestone in Pennsylvania and the Tribes Hill limestone in New York, a zone that so far as it has been recognized agrees better with preceding Ozarkian stages than does any succeeding Canadian submergence. Surface warping and consequent changes in provincial boundaries, that is, in the form and oceanic connections of continental seas, was delayed in this period to the next stage.

Ordovician deposition preceding the period of abundant warping evidently continued through even a longer time. This time is divisible into two stages distinguished by wide differences in sea distribution, but similar in that both indicate gradual submergence. In the first or Saint Peter stage, the submergence was confined to the Mississippi Valley and areas adjacent thereto. Following the first, but preceding the second or Stones River stage, suboceanic spreading caused reemergence of the Mississippi Valley and gradually increasing submergence of the Appalachian, Champlain, and Allegheny troughs on the east and the Arbuckle region in Oklahoma on the south. Continental creep again becoming effective, resulted in rather gradual northward overlap of Stones River deposits. Consequently, while lower, middle, and upper Stones River beds, aggregating between 1,000 and over 1,200 feet of limestone, are found in certain parts of the Appalachian Valley, only late Stones River deposits extend into the upper Mississippi Valley and into central New York and southern Ontario.

That warping occurred during the Stones River is clearly indicated by faunal and stratigraphic studies in the Appalachian tract. These show that Atlantic waters occupied the Champlain Valley during the Crown Point age and also the eastern troughs of the valley in Tennessee, where the Lenoir limestone was laid down. At about the same time Gulf of Mexico waters filled troughs to the west of the Lenoir Bay, and farther north, in the Maryland basin, possibly mingled with Atlantic waters (see table, page 544). Similar movements took place also following the Lenoir and preceding the Pamelia or upper Stones River age, but, on the whole, the displacements of the strandline during the

Stones River are ascribable to continental creep and consequent subsidence of the median areas of the continent.

In the succeeding Blount (upper Chazyan) and Black River stages, however, warping—and therefore shifting of seas—prevailed to an extraordinary degree. Suboceanic spreading had again overcome seaward creep of the land and caused great withdrawal of seas. When they came in again the submergences were for a long time confined to the middle parts of the Appalachian Valley tract and to other troughs nearer the eastern and southern margins of the continent. This restriction is inferred from the sharply limited distribution of the formations and faunas of the Blount group. Moreover, as has been pointed out in other parts of this work, the distribution of the several formations of this group within the general area in which it is represented by deposits, is far from uniform. Obviously, the decided variations are due to surface warping.

The extent and frequency of the warping which characterizes this middle Ordovician period of oscillation is even more clearly expressed by the geographic variability of the post-Lowville Black River deposits. During the Blount stage warping seems to have affected only the now more or less strongly folded submarginal areas. Nor did it transgress these limits in the opening phase of the Black River, for the Lowville, which represents the first age of the Mohawkian, spreads widely and evenly inland and in a manner suggesting median subsidence due solely to continental creep. Compared with the Lowville, the distribution of the succeeding Black River deposits is strikingly irregular. Compared even with each other, the areal patterns formed by the sediments of the Watertown, Decorah, and Kimmswick ages are extremely different. In fact, I know of but a single area, namely, in Hancock County, Tennessee, in which anything like a complete sequence of Black River deposits is to be found.

Disregarding both local and continental tilting, which continued to be a prominent factor of Ordovician diastrophic history to the close of the Mohawkian epoch, relatively even and broad epeirogenic movements became increasingly dominant during the Trenton ages and attained the maximum for the concluding half of the Ordovician during the Cincinnatian.

In the Ordovician, then, we have an introductory stage characterized by gradual submergence of the Mississippi Valley, continued emergence of the Appalachian tract, and absence of warping in areas where the record of such deformation might be preserved; a second stage beginning with submergence of Appalachian troughs and emergence of the Missis-

sippi Valley, and proceeding with occasional warping in the former and gradual resubmergence of more inland areas to the west and north; a third stage characterized by profuse warping and sea shifting which began with the narrow Atlantic seas of the Blount stage, attained maximum development in the Black River and grew less during the Trenton ages of wide interior seas; and, finally, a fourth stage in which the movements were broad in scope, without the irregular effects of regional warping, tending, on the whole, to mid-continental elevation, and in which the submergences were extensive in the Appalachian and Allegheny basins, but fell so far short of preceding stages in northerly and westerly directions that Cincinnatian deposits seem entirely absent in the Mississippi Valley north of Tennessee and west of Indiana.

Except for modifications due to the intervening highly emergent phase marking the transition from the Eopaleozoic to the Neopaleozoic era, a similar series of stages is recognizable in the Silurian. In the latter period the Richmondian corresponds, in a general way, to the "Saint Peter" series, the Clinton to the Stones River, the later Niagaran or Chicago ages to the Black River and perhaps early Trenton, and the Cayugan to the Cincinnatian. The average altitude of the continent during the Silurian being greater than in the Ordovician, the areal extent of most of the Silurian formations is inferior to that of the corresponding formations in the older period. Moreover, and for the same reason, certain well-defined parts of the Ordovician submergent stages seem wholly unrepresented in the accessible depositional sequence of the Silurian in southeastern North America. Most notable of these is the absence of any stage corresponding to the Ordovician Blount group. Nor can I recognize beds whose diastrophic history is comparable to that of the middle and late Trenton.

Whether the early stages of a period effected submergence of median areas of the continent—particularly the Mississippi Valley—depends on the relative average altitude of the continent during the period. (See page 342). If this average was low, as during the Ordovician, then the continental seas were often broad, and the marine sedimentary record in them is correspondingly full; if the average was high, as during the Tennessean, Pennsylvanian, and Jura-Trias, then sea invasions during the period were fewer and smaller and the accessible record correspondingly incomplete.

Applying this idea to other systems, as, for instance, the Waverlyan, we may compare the evenly spread Chattanoogan with the Stones River, the exceedingly oscillating Kinderhookian with the Black River, and the Osagian with the Trenton. In each case the Waverlyan formations

are inferior in geographic extent to the corresponding Ordovician deposits, and so we should not be surprised when it appears that the Waverlyan presents no marine sediments in southeastern North America corresponding to the Cincinnatian. The average altitude having, according to theory, grown greater in the Tennessean, the initial (Warsaw) submergence of this period may well correspond to the oscillating Black River stage in the Ordovician. Under this interpretation, the Tennessean has no accessible deposits comparable to the Saint Peter and Chazyan, while the Chester formations would correspond to the Trenton and possibly early Cincinnatian.

The remaining Paleozoic systems, namely, the Ozarkian, Devonian, and Pennsylvanian, likewise seem to have begun with sedimentary stages, indicating considerable preceding warping. In each of these periods, accessible deposition in continental basins was delayed to at least the second or Stones River stage of the Ordovician sequence. In other words the continental creep subsidence corresponding to the "Saint Peter" invasion in the Ordovician and the Richmondian in the Silurian, did not reach the level at which the Mississippi Valley north of Saint Louis would be submerged. Evidently, the average altitude of the continent during each of these periods was greater than in the Ordovician and Silurian. The same conclusion is suggested already by comparing the maximum extent of the continental seas in each of the Paleozoic periods.

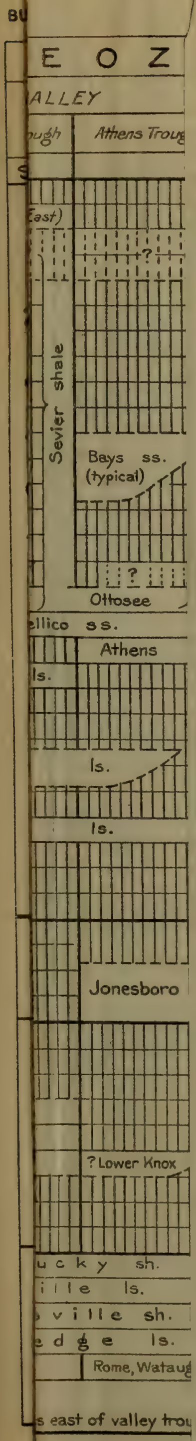
The probable truth of deductions based on these comparisons, is indicated by the fact that whereas the middle Devonian seas spread much more extensively over the median areas of North America than did the others, save the Ordovician and Silurian, the first or Helderbergian series of the Devonian extends northward in the Mississippi Valley to Perry County, Missouri. Depending on the facts in hand, it is inferred that the inaccessibly recorded intervals between the Canadian and the Ordovician and between the Ordovician and the Silurian are shorter than those separating the Cambrian and Ozarkian, the Ozarkian and Canadian, the Silurian and Devonian, and the last from the Waverlyan, and, further, that the interval in all these cases is much shorter than those between the Waverlyan and the Tennessean, and the Tennessean and Pennsylvanian. Rhythmic relationship between these supposedly long and short intervals is suggested, but more study is required before anything of the kind may be said to have been established. Whatever the issue of such studies the great incompleteness of the known stratigraphic record is assured beyond dispute; and it is no less certain that attempts to estimate the length of geologic time, which do not take these unrecorded intervals into account must inevitably fall far short of the truth.

Sequence, Grouping, and Nomenclature of stratigraphic Units in southeastern North America.

GENERAL DISCUSSION

We have now reached the point where the foregoing criteria and principles are to be applied as consistently as may be in the promised reclassification of the stratigraphic sequence in North America. Granting, first, that the old classification is, to a certain extent, wrong in principle; second, that the science of stratigraphy has outgrown the old scheme so far that it no longer fills the requirements of the modern taxonomist, and, third, if we admit the competence of the criteria discussed in preceding parts of this work, reclassification of geologic time seems an imperative necessity. At present, then, the only question is, are the principles which have been deduced from the facts in hand valid enough to insure a reasonable term of stability to the revised conception? In other words, are our facts sufficiently numerous and is my interpretation of the evidence sufficiently true to insure a firm basis for the principles of correlation and taxonomy, and thus for the scheme which has been built upon them? That I think so is apparent, for otherwise I should not have dared to offer it. Yet, realizing the gravity of the occasion, the sanctity of the institution that I am seeking to tear down and replace with what I deem a more natural and more systematically constructed scheme, it is with great diffidence that I present my conclusions. If a defense were necessary, I might point out how I have worked long and hard; first, in gathering the data, of which only a small part could be adequately presented at this time, and, second, to shape my results so that they might be truly constructive and not merely destructive. To what extent I have succeeded time alone may tell. Doubtless, certain parts of my correlation tables will be found defective, if not altogether erroneous, in matters of detail. We may, too, find it necessary to revise them in relatively fundamental features. But, even if it should prove that the work be faulty in important particulars, the effort must still be set down as worth while, because I know it is not all wrong; some of the new principles, at least, are sound. And that is as much as any of us has a right to expect.

Whatever of weakness may hereafter be shown in the proposed classification will probably arise from the fact that it is based chiefly on personal observations in the southeastern quarter of the North American continent. This area, though large, is yet but a small part of the entire globe. On the other hand, it comprises the most complete and best exposed sequence of Paleozoic deposits known. Certain parts of the


E O Z
ALLEY
Athens Troug
Sevier shale
Bays ss.
(typical)
Ottosee
ss.
Athens
ls.
ls.
ls.
Jonesboro
? Lower Knox
sh.
ls.
sh.
ls.
Rome, Watau
east of valley

EOPALEOZOIC

General time scale with provisional units

- SILURIAN — First formation of
- ORDOVICIAN
  - Juniata
  - Cincinnatian — Maysville: McMillan (O), Fairview (O); Eden: Frankfort (N.Y.), Utica (N.Y.)
  - Mohawkian — Trenton: Catheys (T), Perryville (Ky), Flanagan (Ky), Bigby (T), Wilmore (Ky), Hermitage (T), Prosser (Min), Kimmswick (Mo); Black River: Decorah (Ia), Watertown (N.Y), Lowville (N.Y)
  - Chazyan — Blount: Ottosee (T), Tellico (T), Athens (T), Holston (T); Stones River: Carters (T), Lebanon (T), Ridley (T), Pierce (T), Murfreesboro (T), Mosheim (T)
  - Unnamed epoch — Joachim (Mo.), St. Peter (Min), Everton (Ark)
- CANADIAN — Bellefonte (Pa.), Axeman (Pa.), Nittany (Pa.), Stonehenge (Pa.)
- OZARKIAN
  - Upper Ozarkian — Jefferson City (Mo), Roubidoux (Mo.), Gasconade (Mo.)
  - Saratogan — Proctor (Mo), Copper Ridge (Tenn), Potsdam (N.Y)
  - Lower Ozarkian — Potosi (Mo.), Ketona (Ala.), Briarfield (Ala.)
- CAMBRIAN
  - St. Croixan or Upper Cambrian — Nolichucky (Tenn.), Maryville (Tenn.), Rogersville (Tenn.)
  - Middle Cambrian — Rutledge (Tenn.), Russell (Va.)
  - Lower Cambrian

Northern and Middle Appalachian Valley

- **North Central New York:** Medina ss.; Lewiston (Queenston); Oswego ss.; Pulaski f.; Lorraine; Frankfort sh.; Utica shale; Gray ls.; Trenton limestone; Middle Trenton; Prasopora zone; Basal Trenton; Watertown ls.; Lowville; Pamelia ls.; Upper Theresa; Theresa (typical); Potsdam ss.
- **East Central New York:** Clinton; Pulaski; Frankfort; Brayman; Canajoharie sh; Dolgeville; Snake Hill sh; Basal Trenton; Lowville; Tribes Hill ls.; Little Falls dol
- **Champlain Valley:** Shale; Martinsburg; Cumberland Head shale; Basal Trenton; Amsterdam; Upper Lowville; Black River; Valcour ls.; Crown Point ls.; Day Point ls.; Beekmantown (Comprising Divisions E, D, C, and part of B); Little Falls dol (= Division A and part of B); Hoyt limestone; Potsdam ss.
- **Central Pennsylvania:** Tuscarora q'tz.; Juniata ss.; Oswego (Bald Eagle); Shale; Reedsville shale; Trenton ls.; Lower Trenton limestone; Amsterdam; Lowville; Pamelia; Bellefonte dol.; Axeman ls.; Nittany dol; Stonehenge ls.; Cherty dolomite; Kittatinny (Allentown ls.); Unknown; Probable hiatus
- **NE. Pennsylvania Basin:** Shawangunk; Martinsburg shale; Cement rock; Amsterdam; Jacksonburg; Lowville; Normanskill; Beekmantown (Copake); Hill ls.; Kittatinny; Represented by the Hardyston ss.
- **Maryland Basin:** Tuscarora; Massanutten ss.; Red ss. (Eden ss member); Martinsburg shale; Upper Chambersburg; Chambersburg limestone; Lowville; Lower Chambersburg; Stones River group; Beekmantown with Stonehenge member at base; Conococheague f.; Elbrook ls.; Waynesboro f.; Tomstown ls., Antietam ss., Harpers schist, Weverton ss.
- **Central Virginia Basin:** Clinch ss., Clinton; Red ss. (Fairview); Frankfort (Eden); Trenton ls; Liberty Hall; Lowville; Athens; Murat ls.; Limestone and dolomite of Canadian age (Natural Br. ls. in part or whole); Knox dol.; Nolichucky; Honaker ls.; Russell; Buena Vista; Sherwood ls., Quartzites and shales

Tennessee Basin of Appalachian Valley

- **Newman Trough:** Clinton; Fairview (Bays); Frankfort (Sevier); Trenton group; Cannon ls.; Hermitage; Black River group including Lowville; Ottosee; Holston; Stones River gr.; Chickamauga limestone; Not exposed; Probably absent beneath Knox.
- **Clinton Trough:** Clinton; Cannon ls.; Hermitage; ?; Moccasin (Bays); Lowville; Ottosee; Holston; Stones River group; Chickamauga ls.; Upper Knox; Copper Ridge; Lower Knox; Conosauga sh; Rome shale and ss
- **Pearisburg Trough:** Clinch; Shaly ls.; Sevier shale; Shale; Moccasin (typical); Moccasin; Lowville; Heiskell shale; Pearisburg limestone; Holston; Mosheim; Russell sh.
- **Knoxville Trough:** Clinch; (West) (East); Sevier sh.; North of Clinch Mt.; Moccasin; Sevier shale; Lowville; Ottosee sh.; Tellico ss.; Holston ls.; Lenoir ls.; Mosheim ls.; Nolichucky sh.; Maryville ls.; Rogersville sh.; Rutledge ls.; Rome
- **Athens Trough:** Sevier shale; Bays ss. (typical); Ottosee; Sevier; Athens; Chickamauga ls.; Jonesboro ls.; ?Lower Knox; Rome, Watauga; Beaver limestone; Apison shale; (Older Chilhowee sandstones and shales east of valley troughs)

Alabama Basin

- **Murfrees and Birmingham Valleys:** Clinton; Upper Eden; Bigby?; Locally represented; Locally represented; Lowville; Stones River group; Attalla cong.; Chepultepec d.; Knox dolomite; Ketona dolomite; Conosauga shale; Rome; ?
- **Cahaba Valley:** Christiana fauna; Athens (Rockmart); Stones River; Limestone of Canadian age; Chepultepec; Knox dolomite; Potosi; Briarfield dol; "Montevallo"; ?

Cincinnati Geanticline

- **Cincinnati Dome:** Arnheim; McMillan f.; Fairview ls.; Girard ss.; Frankfort sh.; Fulton; Catheys f.; Perryville ls.; Flanagan ch.; Bigby ls.; Wilmore f.; Hermitage f.; Curdsville ls.; Upper Decorah; Lowville (Tyrone); Highbridge limestone; Oregon dol.; Campnelson ls.; (Not exposed); St. Peter (in wells); ?; (Unknown, probably absent)
- **Nashville Dome:** Arnheim; Fernvale; Leipers; Cannon ls.; Nashville group; Hermitage; Kimmswick; Lowville; Carters; Lebanon; Ridley; Pierce; Murfreesboro; Stones River; (Not exposed, probably absent); Wells chert; (Unknown)

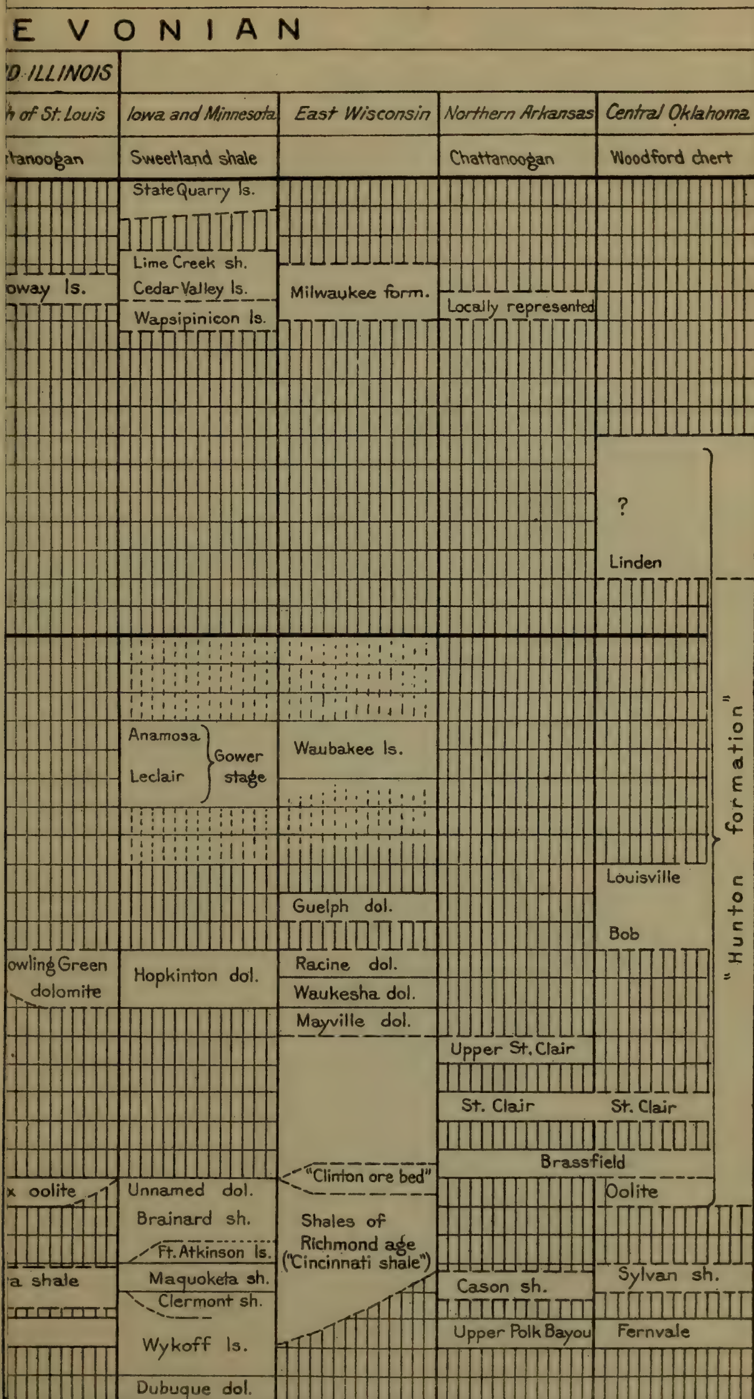
Ozark Uplift

- **South Flank:** Fernvale; Kimmswick; Izard limestone; Joachim; Everton; Yellville formation; Jefferson City; Roubidoux; Gasconade; Proctor; Eminence; Potosi; ?
- **East Missouri:** Fernvale; Maquoketa; McCune dol.; Upper Prosser; Decorah; Bryant ls.; Plattin limestone; Upper Stones Riv; Joachim; St. Peter; Elvins f.; Bonneterre d.; Lamotte ss.

Upper Mississippi region

- **Wisconsin-Illinois lead district:** Dubuque; Maquoketa; Typical Galena dolomite; Galena form.; Decorah; Middle and Upper Platteville; Platteville limestone; "Lower Buff"; St. Peter; Shakopee d; Oneonta dolomite; Jordan (Madison) sandstone; ? Mendota ls; ? St. Lawrence; ?; ? St. Lawrence (Mendota) ls; Dresbach sandstone and shale; Hinckley formation
- **East Wisconsin:** Richmond; Galena dol.; "Upper Blue"; "Upper Buff"; "Lower Blue"; "Lower Buff"; St. Peter
- **Minnesota and North Iowa:** Wykoff; Stewartville dol. (Maclurea bed); Prosser ls.; Decorah sh.; Vanuxemia bed; Platteville; Beloit dol.; "Lower Bluff"; Glenwood sh.; St. Peter; Shakopee dol; New Richmond ss; St. Croix
- **Arbuckle uplift (Oklahoma):** Fernvale; Viola ls.; Bromide; Simpson f.; Main part of Arbuckle ls.; ? Basal Arbuckle; ? Basal Arbuckle; Reagan; Honey Cr. ls. member; ss.

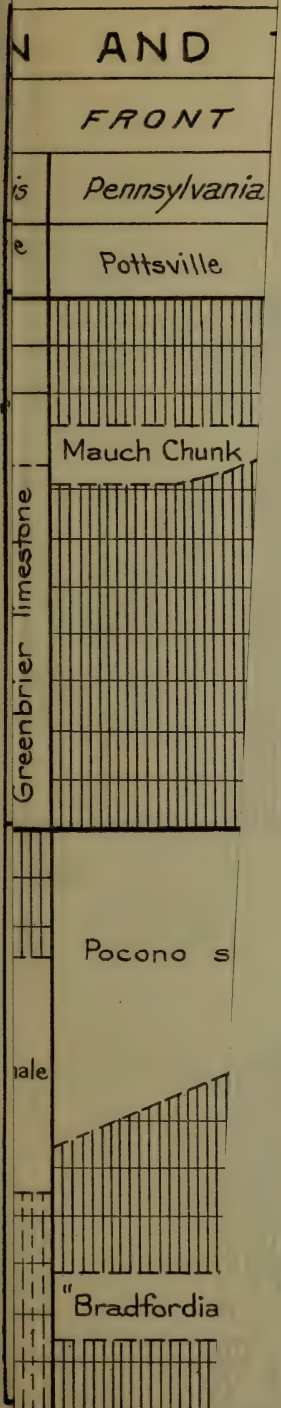
CORRELATION TABLE I


E V O N I A N
D ILLINOIS
h of St. Louis
Iowa and Minnesota
East Wisconsin
Northern Arkansas
Central Oklahoma
ttanoogan
Sweetland shale
Chattanoogan
Woodford chert
State Quarry ls.
Lime Creek sh.
Cedar Valley ls.
Wapsipinicon ls.
oway ls.
Milwaukee form.
Locally represented
?
Linden
Anamosa
Leclair
Gower stage
Waubakee ls.
"Hunton formation"
Louisville
Bob
Guelph dol.
owling Green dolomite
Hopkinton dol.
Racine dol.
Waukesha dol.
Mayville dol.
Upper St. Clair
St. Clair
St. Clair
Brassfield
"Clinton ore bed"
x oolite
Unnamed dol.
Brainard sh.
Ft. Atkinson ls.
Oolite
Shales of Richmond age ("Cincinnati shale")
a shale
Maquoketa sh.
Clermont sh.
Cason sh.
Sylvan sh.
Wykoff ls.
Upper Polk Bayou
Fernvale
Dubuque dol.

NEOPALEOZOIC — SILURIAN AND DEVONIAN

General time scale				New York: Western New York	New York: Central and Eastern N.Y.	Appalachian Valley: Penn. Md. and Va.	Appalachian Valley: Tennessee-Alabama	West Tennessee	Ohio Valley: West of Cincinnati	Ohio Valley: Eastern Kentucky and Southern Ohio	Ohio Valley: Northern and Central Ohio	East Missouri and Illinois: South of St. Louis	East Missouri and Illinois: North of St. Louis	Iowa and Minnesota	East Wisconsin	Northern Arkansas	Central Oklahoma
Waverlyan system			First formation of	Bradfordian	Pocono (? Catskill)	Pocono-Upper Grainger	Upper Grainger-Chattanooga	Chattanooga	Upper New Albany	Chattanooga shale	Cleveland shale	Chattanoogan	Chattanoogan	Sweetland shale		Chattanoogan	Woodford chert
Devonian	Neodevonian	Seneca	Chemung (N.Y.)	Chemung f.	Catskill	Chemung; Jennings form.	Partly represented in Chattanooga and Grainger formations in N.E. Tennessee; Absent in Alabama		Lower New Albany shale		Chagrin f.			State Quarry ls.			
			Portage (N.Y.)	Portage f.	Enfield, Ithaca, Sherburne; Oneota	Portage						Black sh. and ls. (local)					
			Genesee (N.Y.)	Genesee sh.	Genesee sh	Genesee				Lower part of Ohio shale							
			Tully (N.Y.)	Tully ls	Tully ls.									Lime Creek sh.			
	Mesodevonian	Romney Erie	Hamilton (N.Y.)	Hamilton sh	Hamilton sh. and ss.	Hamilton; Romney			Sellersburg ls. Silver Creek dol.		Olentangy sh.		Calloway ls.	Cedar Valley ls.	Milwaukee form.	Locally represented	
			Marcellus (N.Y.)	Marcellus sh.	Marcellus	Marcellus				?	Delaware ls. ------ shale	? Grand Tower limestone		Wapsipinicon ls.			
		Ulster	Onondaga (N.Y.)	Onondaga ls.		Onondaga		Pegram ls.	Jeffersonville ls.	Boyle ls	Columbus ls.						
			Schoharie Decewville (N.Y.)		Schoharie				Geneva ls.			?					
	Eodevonian	Oriskany	Esopus (N.Y.)		Esopus	Oriskany group ss. and chert	Frog Mtn ss. (N.E. Alabama)	Clear Creek (Camden) ch.				Clear Creek ch.					
			Glenerie (N.Y.)		Glenerie												
			Connely (N.Y.)		Connely												
			Port Ewen (N.Y.)		Port Ewen												?
		Helderberg	Becraft (N.Y.)		Becraft f.												
			New Scotland (N.Y.)		New Scotland f.			Linden f.				Bailey ls.					Linden
			Coeymans (N.Y.)		Coeymans ls.												
			Keyser (W.Va.)		Keyser ls.												
Silurian	Cayugan	Upper Cayugan	? Manlius (N.Y.) (Tentaculite ls.)		"Tentaculite ls" "Cement rock" Cobleskill ls.	? Bassardville ls.	Sneedville ls.			Greenfield (in Ohio)	Lucas form. (May be Devonian)						
			Tonoloway (Md)			Tonoloway ls.											
			Wills Creek (Md)	Akron dol.		Wills Creek f.											
			Bloomsburg (Pa.)	Bertie wl.		Bloomsburg ss				Hillsboro ss.	Sylvania ss.			Anamosa; Gower stage	Waubakee ls.		
		Lower Cayugan	Bass Island (O)								Bass Island: Put-in Bay, Tymochtee			Leclair			"Hunton" formation
			Salina (McKenzie) (N.Y.) (Md.)	Salina: Camillus, Syracuse, Vernon, Pittsford	Longwood sh. Shawangunk	McKenzie form.		Decatur ls.			Salina						
	Niagaran	Chicago	Louisville (Ky)				? Louisville coral zone	Louisville ls.			(Undetermined)						Louisville
			Guelph (Can)	Lockport dol.						Cedarville dol.		?			Guelph dol.		
			Bob Beech River (Tenn)					Bob Beech River		? Springfield d.		Bainbridge ls.					Bob
			Racine (Wis)									?	Bowling Green dolomite	Hopkinton dol.	Racine dol.		
			Waukesha (Wis)					Dixon							Waukesha dol.		
			Waldron Laurel (Ind.)					Waldron Laurel				?			Mayville dol.		
		Clinton	Rochester (N.Y.)	Rochester	Typical Clinton formation	Clinton group	Clinton (Rockwood)	Osgood		West Union						Upper St. Clair	
			Williamson (N.Y.)	Williamson													
			St. Clair (Ark)	Wolcott ls.						Dayton; Crab Orchard						St. Clair	St. Clair
			Sodus (N.Y.)	Sodus sh.													
			Brassfield (Ky)	Rhinopora beds				Brassfield				Brassfield				Brassfield	
			Noix (Mo.)	Medina ss.	Oneida	Medina or	Clinch ss.					Noix ls.	Noix oolite	Unnamed dol.	"Clinton ore bed"		Oolite
			Girardeau (Mo)			Tuscarora ss.		?				Girardeau ls.		Brainard sh.	Shales of Richmond age ("Cincinnati shale")		
			Saluda and Whitewater					Saluda-Whitewater	Saluda					Ft. Atkinson ls.			
			Maquoketa (Ia.)					? Mannie sh.				Thebes form	Maquoketa shale	Maquoketa sh.		Cason sh.	Sylvan sh.
			Liberty and Waynesville						Liberty-Waynesville					Clermont sh.			
			Fernvale (Tenn)					Fernvale				Fernvale		Wykoff ls.		Upper Polk Bayou	Fernvale
			Arnheim (O.)						Arnheim								
			Dubuque (Ia.)											Dubuque dol.			

CORRELATION TABLE II



N AND
FRONT
is
Pennsylvania
e
Pottsville
Mauch Chunk
Greenbrier limestone
Pocono s
iale
"Bradfordia

NEOPALEOZOIC — WAVERLYAN AND TENNESSEAN

General Time Scale			Mississippi Valley: South of St. Louis	Mississippi Valley: North of Cap-au-Gris	Indiana Basin	Middle Tennessee	Allegheny Front: South of Wytheville Axis	Allegheny Front: North of Wytheville Axis	Allegheny Front: Pennsylvania	Appalachian Valley: NE. Alabama	Ohio Basin	Ozark Uplift: Southwest Flank	Ozark Uplift: Northwest Flank	Oklahoma: Arbuckle Uplift
Pennsylvanian		First formation of	Mansfield ss.	"Upper Pottsville"	Mansfield ss.	? Lookout ss.	Walden ss. Lookout ss.	Lee conglomerate Pocahontas f.	Pottsville	Lower Pottsville	Late Pottsville cong.	Hale ss. Cherokee shale	Cherokee shale	Jackfork Stanley Caney shale
Tennessean	?	Bluestone (W.Va.)						Bluestone		Parkwood f.				
Tennessean	?	Princeton (W.Va.)						Princeton						
Tennessean	Chesterian, Birdsville	Pitkin (Ark.)	Birdsville f.; Kaskaskia		Birdsville	Highland rim capped by Chester formations	Bangor limestone; Newman limestone; Monte Sana; Pennington shale	Pennington shale	Mauch Chunk	Pennington sh. Limestone Hartselle ss.; Floyd shale		Pitkin ls.; Carterville		
Tennessean	Chesterian, Birdsville	Fayetteville (Ky.)										Fayetteville f.		
Tennessean	Chesterian, Monte Sana	Tribune (Ky.)	Tribune ls.		Tribune ls.; Mitchell ls.		Limestone	Limestone; Greenbrier limestone		Limestone; Bangor limestone; ?				
Tennessean	Chesterian, Monte Sana	Cypress (Ill.)	Cypress ss.		?							Batesville ss.		
Tennessean	Chesterian, Monte Sana	Ste. Genevieve (Mo.)	Ste. Genevieve form. Pella ls.		?						Maxville ls.			
Tennessean	Meramecian	Moorefield (Ark.)										Moorefield sh.		Sycamore ls.
Tennessean	Meramecian	St. Louis (Mo.)	St. Louis ls.		St. Louis ls.	St. Louis								
Tennessean	Meramecian	Spergen (Ind.)	Spergen limestone		Spergen ls.	Spergen				Limestone				
Tennessean	Meramecian	Warsaw (Ill.)	Warsaw formation		Warsaw ls.; Harrodsburg ls.	Warsaw	Limestone	Limestone				Short Cr. oolite and overlying limestone		
Waverlyan	Osagian	Keokuk (Ia.)	Keokuk formation		Keokuk	Fort Payne ch.	Ft. Payne chert			Fort Payne chert	Logan ss. Black Hand cong.	Grand Falls ch.; Boone chert	?	
Waverlyan	Osagian	Late Burlington (Ia.)		Upper Burlington ls.		Tullahoma (H. and U.)						Limestone and chert	Burlington ls.	
Waverlyan	Osagian	Early Burlington (Ia.)	E. Burlington	Lower Burlington					Pocono ss.			St. Joe member		
Waverlyan	Osagian	Fern Glen (Mo.)	Fern Glen f.	?	Riverside ss New Providence sh.	New Providence						Fern Glen	?	
Waverlyan	Kinderhookian	Chouteau (Mo.)		?				Upper Grainger shale			Cuyahoga f.	? Chouteau	Chouteau ls.	
Waverlyan	Kinderhookian	Hannibal (Mo.)	? Bushberg ss.; Sulphur Springs form.	Hannibal sh; Kinderhook								Hannibal f.		
Waverlyan	Kinderhookian	Glen Park (Mo.)	Glen Park ls.	Glen Park ls.	Rockford ls.									
Waverlyan	Kinderhookian	Louisiana (Mo.)		Louisiana ls.		Ridgetop sh.						? Fine grained ls. Sac ls King ls. Phelps ss.		
Waverlyan	Chattanoogan	Sunbury (O.)	Chattanooga black shale	Sweetland sh.	Upper part New Albany shale	Chattanooga; Maury shale	Chattanooga shale	?	"Bradfordian"; Late Catskill	Chattanooga shale	Sunbury sh.	Chattanooga f. (James R. sh.); Sylamore ss. member		Woodford form.
Waverlyan	Chattanoogan	Berea (O.)				Black shale					Berea grit			
Waverlyan	Chattanoogan	Bedford (O.)									Bedford sh.			
Waverlyan	Chattanoogan	Cleveland (O.)				Hardin ss.					Cleveland sh.			

CORRELATION TABLE III

column, doubtless, are more fully developed in the Cordilleran troughs of western America, but, taken as a whole, neither the Cordilleran nor any other area offers so complete and clear a record of Paleozoic history. Certainly no European area is comparable in these respects, and none anywhere is, therefore, so well fitted to furnish the world standard.

In this connection I may mention the Baltic section, which is generally referred to as a very complete record of pre-Devonian Paleozoic depositional and faunal history. In fact, however, it is far from being so. Whole chapters are missing, and it is greatly inferior to the Appalachian record. Compared with the composite pre-Devonian section as now worked out in southeastern North America the Baltic sequence may be described as consisting of epitomized quotations from the sedimentary record of the Arctic and North Atlantic seas. Though beautifully punctuated with well preserved fossil faunas and worked out in great detail by the Swedish and Russian geologists, the Baltic record yet presents only one-sided, biased testimony, rendering it unfit to rank as a standard for the world. Contrasted with the corresponding American sedimentary record, the Baltic section is inferior in every respect, and greatly so in most. In view of these facts, the recent proposal by Moberg to revive the Murchisonian conception of the Silurian; that is, a Silurian embracing all the rocks from the base of the Cambrian to the base of the Devonian, seems too much like wiping out the results of fifty years of work in stratigraphy to be entertained for a moment.

GENERALIZED STATEMENT OF PROPOSED CHANGES

In constructing the new classification sentiment has played but a small part. My endeavor has been to apply the adopted principles in rigorous and consistent accord with my conception of the facts. So far as my information extends, the result is a fair test of the application of diastrophism in determining the essential contemporaneity of geologic events and of the claims of those who believe that the criteria which imply crustal movements offer the only reliable, or, as Chamberlin would express it, the "ultimate," basis of stratigraphic classification.

Of the new features of the proposed classification the most conspicuous, perhaps, is the great expansion of the pre-Devonian parts of the stratigraphic column. Many new units, ranging in rank from systems or periods down to formations or ages, are intercalated in the time scale. A part of this expansion is by discovery of formations hitherto overlooked; but the greater part is by placing units either above or beneath those of the current standard with which they have till now been correlated. Most of the latter changes are based on positive stratigraphic

relations which disprove the hitherto supposed contemporaneity of the concerned formations. The methods employed in determining these relations are explained and illustrated by examples in discussing the principles of correlation by diastrophic movements. A few, finally, are based mainly on hypothetical grounds. Of the last only the group containing the Saint Peter sandstone and the Niagaran series, some of which are thought to be older, others younger, than was assumed heretofore, are of sufficient consequence to be likely to excite adverse comment.

The most important changes in the grouping of formations occur in the Eopaleozoic part of the column. Here the great expansion of the stratigraphic sequence supplies the main grounds for the proposed division of the era into four sharply defined periods or systems, instead of the two, Cambrian and Ordovician, hitherto recognized. The two new systems, for which the names Ozarkian and Canadian have been selected, are not, as may be supposed, instituted by mere subdivision of the stratigraphic units previously comprised in standardized Cambrian and Ordovician sections, but they are composed mainly of formations whose stratigraphic positions had been misinterpreted and whose aggregate thicknesses had been greatly underestimated. The facts are presented in sufficient fullness in other chapters. Also those furnishing the basis for the proposed division of the Mississippian into two systems, for the denial of systemic rank to the Permian and for the union of the Triassic and Jurassic in a single system. I follow Chamberlin and Salisbury and Schuchert in recognizing the Comanchean system. They and other authors are followed in dividing the Cenozoic or Tertiary into two systems.

In the classification recently proposed by Schuchert the Eopaleozoic is divided into six systems, the Cambrian as here recognized being divided into the "Georgic" and "Acadic" systems, and the post-Mohawkian part of the Ordovician of the present work being united with the Richmondian to make a "Cincinnatic" system. I regret exceedingly that I can not accept these innovations. To do so would mean the sacrifice of consistency, which I deem the chief merit of my scheme. Though avowedly based on diastrophic principles, I shall endeavor to show presently that the evidence relied on in these cases by Schuchert is not so important as he conceives.

Beginning with the Cambrian, the fourteen systems or periods are grouped into four eras, in the midst of the last of which—the Cenozoic—we are now living. The completed three preceding eras comprise each four systems, as follows: The Eopaleozoic, including the Cambrian, Ozarkian, Canadian, and Ordovician; the Neopaleozoic, including the

Silurian, Devonian, Waverlyan, and Tennessean; the Mesozoic, including the Pennsylvanian, Jura-Triassic or Newarkian, Comanchean, and Cretaceous. The proposed downward extension of the Mesozoic so that it will begin with the Pennsylvanian will probably arouse more opposition than the reduction of the Permian, the Triassic, and the Jurassic to the rank of series. But a strict and entirely consistent application of the principles of correlation by diastrophic movements demanded nothing less. If, in following their lead, I have fallen into error, it is either because the principles are at fault—which I am loath to believe—or because the available data have been misinterpreted. With my present information these, as well as all the other proposed changes, are confidently believed to tend toward the coordination of the major divisions of the geologic time scale. And this feature is deemed a prime desideratum, if, indeed, it is not a requisite, in the construction of a permanent classification.

Eopaleozoic Formations

CAMBRIAN SYSTEM OR PERIOD

Definition of the term Cambrian.—It is not my intention to enter into an extended discussion of the varying uses of this term. Beyond making it clear which part of the stratigraphic column I am referring to when the word Cambrian is used, it will suffice to say that as proposed and commonly used by Sedgwick, the author of the term, it corresponded practically to the Eopaleozoic of Dana and the present work, and of the Eopaleozoic, and, in other parts of his recent work, of the restricted Paleozoic, of Schuchert. Following the indefinite separation of an upper part of the Eopaleozoic by Lapworth under the name Ordovician, an innovation that has been generally adopted in America where it displaced the previously used "Lower Silurian," the Cambrian was correspondingly restricted. But a definite boundary between the Cambrian and the Ordovician was never satisfactorily established. Some drew the lower limit of the Ordovician at the base of the Saint Peter sandstone, others thought it should be drawn somewhere between the middle and base of the Canadian, while others again limited the Cambrian to deposits beneath some undetermined and variously correlated middle or lower Ozarkian zone.

As here used, the term Cambrian refers to strata beginning with the basal part of the oldest formation containing the "Olenellus fauna" or trilobites belonging to the family *Mesonacidæ*. The upper boundary is drawn at the apparently universally recognizable hiatus, which marks the

top of the Nolichucky in east Tennessee, the top of the Conasauga in Alabama, the top of the Elvins in Missouri, the top of the Saint Croix in Minnesota and Iowa, the top of the Honey Creek member of the Reagan formation in Oklahoma and central Texas, the top of the Bliss sandstone in western Texas and the top of the Deadwood formation in the Black Hills and Big Horn Mountains section in Wyoming. Not having seen the Cordilleran sections, I find it difficult to decide just where to draw this boundary in, say, Walcott's House Range section in Utah. Hazarding an opinion, I would say that his Notch Peak formation is Ozarkian and the Orr formation upper Cambrian.

It may be observed that the Cambrian as here defined accords fairly well with the Cambrian of Walcott as used by him in classifying formations to the west of the Mississippi.[77] Except that he seems inclined to include a portion of the Knox, it accords, also, with his usage of the term in the Appalachian Valley. The chief difference concerns the New York section, where Walcott embraces the Potsdam sandstone and the Hoyt limestone in a Saratogan series and proceeds to correlate this series with the "upper Cambrian" elsewhere in the country. As recently shown by Ulrich and Cushing,[78] there is neither a faunal nor a stratigraphic break[79] between the Potsdam and the Little Falls dolomite, of which the Hoyt limestone is merely a locally distinguishable member. It is shown further that the Saratogan, including the Little Falls dolomite, is really the equivalent of middle parts of the Ozarkian section in Missouri, and that it is, therefore, much younger than the beds in Missouri, Texas, Oklahoma, and Wyoming, which Walcott formerly and now refers to the upper Cambrian. It is merely a case of mistaken correlation, an error of judgment that in the absence of detailed knowledge respecting the stratigraphy and the faunal and diastrophic history of the late-Cambrian to early Ordovician deposits, he could hardly have escaped. Relying on the New York section, in which he noted (1) the essential continuity of sedimentation from the Potsdam sandstone on through the Theresa passage beds into the Hoyt limestone and from this into the supposedly Ordovician dolomite of the Little Falls ("Calciferous") formation, and (2) the apparent Cambrian aspect of the Hoyt fauna, Walcott properly inferred that the Cambro-Ordovician boundary was hidden somewhere in the mass of the Knox dolomite, the lower part of

[77] C. D. Walcott: Proc. Washington Acad. Sci., vol. i, 1900, p. 304.

[78] E. O. Ulrich and H. P. Cushing: Age and relations of the Little Falls dolomite (Calciferous) of the Mohawk Valley. Bull. New York State Mus., No. 140, 1909.

[79] The conformable relations of the Little Falls dolomite and the Potsdam sandstone have been repeatedly admitted by Walcott.

which he knew contained a Saratogan fauna, while some upper bed of the same held gastropods and cephalopods universally accepted as post-Cambrian fossils. Under the prevailing bipartite division of the Eopaleozoic the mollusks were naturally assigned to the Ordovician.

The Saratogan age of the lower part of the Knox having been recognized, and, as Walcott believed, that equivalent beds occurred in the Mississippi Valley, in central Texas, and in the Black Hills, the first and second beneath dolomitic limestones, commonly referred to as corresponding to the New York "Calciferous," it was to be expected that the shales and limestones underlying the Knox and resting on the Rome in east Tennessee and Alabama were, for the most part, referred by him to the middle Cambrian. Only the upper division of this limestone and shale sequence, the Nolichucky shale, was commonly placed in the upper Cambrian.[80]

Recent studies have practically established that the Rogersville shale, the Maryville limestone, and the Nolichucky shale of the Appalachian Valley section in east Tennessee, represent an epoch of great transgression of Cambrian seas. It is this sea—I hope it may be called the Saint Croixan—that swept up the Mississippi Valley to Minnesota[81] and that laid down the first Paleozoic marine sediments in Missouri, in central and western Oklahoma, in central and western Texas, and in the Black Hills and Big Horn Mountains of Wyoming. Whether submergent conditions obtained in the great Cordilleran basin of the west during this time is not altogether certain, but in the Appalachian Valley the evidence shows conclusively that the Saint Croixan is confined to the Tennessee and Alabama basins. Relying on general faunal similarities and apparent agreement in stratigraphic position, the deposits resulting from this transgression have, in most instances, been referred by Walcott to the late middle and upper Cambrian. Viewed from the standpoint of diastrophism, I fail to see a sufficient reason for calling any part of the Cambrian section in the Mississippi Valley, in Oklahoma, and in central Texas middle Cambrian. On the contrary, conceding the probable high average altitude of the continent during the Cambrian, the broad but very shallow Saint Croixan seas make an ideal close of Cambrian submergent phases of American continental basins. The deposits in these shallow mid-continental depressions, therefore, constitute a perfectly

[80] Journal Geology, vol. xi, 1903, p. 319.

[81] Besides a number of unclassified trilobites the following brachiopods are common to the upper Cambrian Conasauga shale in the Appalachian Valley and the Saint Croixan deposits in the Mississippi Valley: *Obolus lambornei*, *O. sinæ*, *Westonia ella*, *Lingulella similis*, *L. desiderata*, and *Lingulepsis acuminata*. A variety of the last is found also in the Ozarkian in both provinces.

satisfactory upper Cambrian, an upper Cambrian that is definitely distinguished from the middle Cambrian by crustal movements whose effect in displacing the Cambrian strandline is recognizable everywhere in North America to the east, and probably also to the west, of the Rocky Mountains. In short, this proposed boundary between the middle and upper Cambrian gives us a definite diastrophic line in place of the variously or indefinitely drawn line of the past. But the upper Cambrian or Saint Croixan of this work is in nowise the same as, nor is any part of it of the age of, the typical New York Saratogan.

Relations of the Cambrian to the Ozarkian.[82]—So long as the Eopaleozoic was divided in but two systems, the only proper boundary between them should have been the one here used in separating the Ozarkian from the Canadian. But no two stratigraphers who had studied the problem and were independent enough to form an opinion of their own seemed able to recognize the boundary at the same position in the column and to draw it consistently from place to place. Several matters were responsible for this uncertainty. In the first place, the stratigraphy and interrelations of the deposits which are younger than the Nolichucky in the Appalachian Valley, the Elvins formation in Missouri, and the Saint Croix series in Minnesota, Iowa, and Wisconsin, and older than the base of the Saint Peter sandstone series was quite misunderstood. Moreover, the aggregate volume of the intervening beds was greatly underestimated, and their faunal history almost unknown. A few trilobites and brachiopods were found in the Knox dolomite in Tennessee and in the Saratogan series in New York, and as these belonged mostly to well known, though rather broadly conceived, Cambrian genera the beds containing them were placed in that system. When well developed gastropods and cephalopods were found, then the outcrop was stated to be of the upper part of the Knox, which, being recognized as "Calciferous," made them post-Cambrian. Had it been known that the "Cambrian" trilobites and the "Ordovician" mollusks are interbedded in the Ozarkian section in Missouri and the Appalachian Valley, a truer conception of the facts would long ago have been attained.

In the course of several seasons devoted to field studies in southern Missouri a large and varied fauna has been collected from the stratigraphic interval overlying the unquestioned Cambrian and underlying the base of the Saint Peter sandstone. Excepting a few species described

[82] The organic and physical principles chiefly involved in the division of the Eopaleozoic into four systems instead of two are discussed in a recent paper by Ulrich and Cushing on the age relations of the Little Falls dolomite, published in New York State Museum Bull. 140, 1909, pp. 130-136.

from the "Lower Magnesian" farther north and those collected from what is now known as the Hoyt limestone near Saratoga, New York, and described by Walcott, most of which were recognized in a middle division of the Missouri section, this large fauna is entirely new to science. Viewing only the trilobites, it must be called a typical development of the Dikellocephalus fauna; and if by that designation we refer to the typical Saratogan development of crustacean life, the appellation is fully justified when applied to this Missouri facies. Though Dikellocephalus-like trilobites occur in the underlying upper Cambrian beds in Missouri as elsewhere, it yet seems a fact that the typical *D. minnesotensis* section of the genus is confined to the Ozarkian part of the time scale. Beneath its first occurrence in the latter there is in Missouri at least one formation—the Potosi—and in Alabama three formations aggregating over 2,000 feet of dolomitic beds, in which neither type of the genus has been observed. Nor is the upper Cambrian type of the genus known to occur above this unfossiliferous interval. Ample time, therefore, intervened between the two occurrences to render it reasonably certain that the presence of *D. minnesotensis* or of closely affiliated species is diagnostic of the Ozarkian period. And there are other derivatives of Cambrian trilobites which, whether viewed as generically or but specifically modified, appear to be no less characteristic of the Ozarkian.

But it is the advent of a host of gastropods and cephalopods, of types entirely unknown in true Cambrian rocks, that stamps the Ozarkian as a new period in geologic history. Small coiled shells, with depressed spires and but one or two whorls—probably heteropods which have been wrongly associated with the genus *Platyceras*—are found occasionally in the Cambrian and up to the middle of the Ozarkian. Patelloid gastropods also are found in the Cambrian and apparently maintained an unbroken line to the present day. But high-spired *Pleurotomariidæ*, likewise low-spiried Liospira-like types of this family, also well developed *Raphistomidæ*, *Euomphalidæ*, and Holopea-like forms, these are seen for the first time in the Ozarkian. The cephalopods, though obviously of primitive types, are yet readily comparable in average size and character with their Canadian and Ordovician descendants. They first become abundant somewhat later than the gastropods, but both classes had attained fair development in Missouri before the typical Saratogan trilobite fauna became established there; and they reached the highest development recorded in the period before *Dikellocephalus* passed out of existence.

The sequence and aggregate thickness of deposits in the Appalachian Valley referred to the new Ozarkian system have been set forth at

sufficient length in preceding parts of this work. (See especially pages 546 to 550.) From these statements and others that are to follow it is clear that the Ozarkian in this province is not only sharply distinguishable from the Cambrian below, but also from the Canadian, or, if this is absent, from the Ordovician above it. It should be apparent further that the importance of the Ozarkian, as determined by such criteria as relative volume of sediments, their time value, and areal distribution, is scarcely if at all inferior to that of the Cambrian or, indeed, any other system found in America. Counting up the maximum thickness of the several formations assigned to the Ozarkian in the Appalachian region, the aggregate is certainly not less than 6,000 feet. Considering that all of this great thickness of sediment is composed of dolomites and limestones, it surely seems that on this ground alone the Ozarkian is entitled to rank as a distinct system. That is has its own well marked fauna has been stated above. We need but to add that its diastrophic history is complete in itself, and, though different in details, comparable in its stages to those recognized in other fully developed systems. Besides, it is separated from the Cambrian below and the Canadian above by long emergent stages that are indubitably recorded in every competent section that I have had an opportunity to study. If these features are not the attributes of a geological system, then stratigraphy is less of a science than I think it.

Major divisions of the Cambrian.—The Cambrian system in America is usually divided into three series: (1) the lower Cambrian, rather generally known as the Georgian; (2) the middle Cambrian or Acadian, and (3) the upper Cambrian, for which the geographic term Saratogan, on the groundless belief of their equivalence, has in recent years gained wide acceptance. The lower Cambrian, for which I hesitate to use the alternative term Georgian, because the same name was originally proposed, and is even now in use, for a subordinate part (Georgia slate) of the lower Cambrian,[83] evidently attained its greatest known development in the Cordilleran trough. Walcott has measured and published descriptions of a number of good sections in Nevada, California, Utah, and British Columbia,[84] the series in each case being subdivided into formational units based on lithologic criteria. As yet the stratigraphic and faunal histories of these several outcrops are insuffi-

[83] I had considered the advisability of using Taconian in place of Georgian, but found many valid objections to the revival of Emmons's term Taconic in any sense. Doubtless a much better name for the series would be Safford's term Chilhowee.

[84] C. D. Walcott: Cambrian sections of the Cordilleran area: Smithsonian Miscellaneous Collections, vol. liii, 1908.

ciently known to decide as to which contains the oldest beds and the most complete sequence of deposits. It seems certain, however, that Cambrian sedimentation began earlier in parts of the Cordilleran basin than in the Appalachian troughs, or in any other region in which rocks of this period are known. For details concerning the lower Cambrian deposits in western North America the reader is referred to Walcott's description in the paper cited.

Lower Cambrian deposits in southeastern North America.—The lower Cambrian depositional sequence in the Appalachian tract has been fairly well worked out in three areas. Beginning in the north, the first of these is in Washington County, New York, and in the vicinity of Georgia, Vermont. The base of the section here is unknown. As worked out by Walcott, the lowest exposed formation is a limestone about 1,000 feet thick. This is succeeded by 200 feet of "Georgia shale," and over this comes 3,500 feet of shale and thin limestone. A quartzite 50 feet thick follows and is in turn overlain by 1,700 feet of limestone and shale, and this by 3,500 feet of shale. I have seen only the upper part of this section, namely, the heavy bed of shale last mentioned, which, together with all the underlying beds, has been referred to the lower Cambrian by Walcott. Regarding this upper shale I am strongly inclined to view it as of Canadian age rather than Cambrian. There is some question in my mind, also, concerning the age of a limestone supposed to belong to the 1,700-foot bed. It contains small bivalved phyllopods (*e. g., Indiana dermatoides* (Walc.), *I. pyriformis* Matth., *I. secunda* M., *Bradoria scrutator* M.), which are characteristic of lower Acadian zones in New Brunswick and Newfoundland. As it is not yet decided whether the Protolenus zone is late lower Cambrian or early middle Cambrian, the exact age of the Vermont bed mentioned also remains uncertain. Besides, the structural geology of Vermont and of the Taconic area in general is very complicated, so that it is not unlikely that future investigations may bring about considerable modifications of the Eopaleozic sequence now accepted for that region.

The lower Cambrian sequence, exposed in and along the foot of South Mountain in Pennsylvania, Maryland, and northern Virginia, is probably more accurately determined than the Vermont section. Besides, the section here exposes the base in contact with pre-Cambrian rocks. Beginning with the arkosic Loudon formation, the section consists in the order of deposition of (1) the Weverton sandstone, which in places may include the horizon of the Loudon and then attains a thickness of about 1,250 feet; (2) the Harpers schist, with a maximum thickness of 2,750

feet; (3) the Antietam sandstone, 700 feet thick, and (4) the Tomstown limestone, with an estimated thickness of 1,000 feet. Sufficient fossil evidence has been procured from these formations to make it reasonably certain that they all belong to the lower Cambrian. The last is succeeded by the Waynesboro formation, which is thought to be middle Cambrian.

Apparently these lower Cambrian formations lap out northwardly from South Mountain, so that finally only the Harding sandstone, which may be a diminishing extension of the Antietam sandstone, represents the epoch in northern New Jersey.

The third well developed lower Cambrian sequence in the Appalachian region is found in Chilhowee and other mountains which form the eastern rim of the valley of east Tennessee. Apparently this almost continuous chain of mountains is a large remnant of a great westwardly thrust mass, of which smaller remnants are found to the north in Virginia and to the south in Georgia and Alabama. The base of the Cambrian is not shown in Chilhowee and Starrs Mountains, but the lowest exposure is probably not far above it. Following the range northeastward to Carter County, the basal formation, here called the Snowbird, is found resting on an Archean granite.

The Chilhowee sequence, as described by Hayes in the Cleveland folio and Keith in the Knoxville and Loudon folios, begins with a shale of undetermined thickness. This is followed in turn by the Starrs conglomerate, 660 feet; the Sandsuck shale, about 1,000 feet; the Cochran conglomerate, 1,600 feet; the Nichols shale, 800 feet; the Nebo sandstone, 500 feet; the Murray shale, 300 feet, and the Hesse sandstone, 500 feet, giving a total thickness of approximately 5,500 feet. In the Roan Mountain quadrangle, as described by Keith in Folio No. 151, the sequence is much the same, excepting that the Sandsuck shale and Starrs conglomerate are not recognized. Instead, the Cochran conglomerate is underlain by the Hiwassee shale, 300 to 1,500 feet thick, and the Snowbird formation, 700 to 2,000, which, as already stated, rests on the Cranberry granite of Archean age. In this folio the Shady limestone is represented as following the Hesse sandstone.

To the west of Chilhowee Mountain—that is, in the valley proper—the Rome sandstone is underlain by two formations supposed to be of lower Cambrian age. These are, namely, the Beaver limestone, 500 feet or more in thickness, and beneath this the Apison shale, of which something like 1,500 feet are seen. Whether these two formations correspond to the formations of the Chilhowee series or represent hiatuses in the Chilhowee section or whether they are really, as is commonly supposed,

about equivalent to the Shady limestone, hence younger than the Hesse sandstone, has not been determined. My tentative view inclines to the second of these possibilities rather than the first and third. The Shady limestone in that event would be younger.

Acadian or middle Cambrian faunas and deposits.—Like the lower Cambrian, the middle Cambrian series also attained its greatest development in western North America. Walcott has described the sections in considerable detail and has gathered an amazingly rich and varied fauna which is in course of study and publication. The fossil treasures which have rewarded his unflagging zeal, especially the beautifully preserved collections made in the vicinity of Mount Stephen in British Columbia, tend to show that after all we know but a small part of the life that teemed in the permanent oceanic basins and which invaded the relatively occasional continental seas only when physical conditions were favorable. Crustacean and other types are found in the Mount Stephen formation whose origin was hitherto believed to be much less ancient. Such discoveries show, as nothing else can, the danger of relying implicitly on the general composition of a fauna in determining the age of the beds containing it. For, if a fauna or any of its generic or specific types can be shown to have existed at earlier dates than the accepted, then it is perhaps even more—certainly no less—likely that they continued to exist somewhere for long or shorter periods after their apparent extinction in the standard section. It seems to me especially unsafe to assume that a genus or family of vigorous organisms was universally exterminated at the close of an intrasystemic epoch or even in the ordinarily longer intervals between most of the periods. Such effective faunal breaks probably occurred in a marked degree only at the time of the diastrophic revolutions which define the eras of geologic time.

A case in point is brought out by the prevailing practice of referring all beds containing *Mesonacidæ* save *Paradoxides,* to the lower Cambrian. If an Atlantic branch of the family could survive the presumably stressful transition from the lower to the middle Cambrian, namely, by modification to the Paradoxides facies, why may not a Gulf of Mexico or a Pacific type of the family have similarly maintained its existence? How may we decide whether either did or did not? So far as I can see, the only competent way is by means of purely diastrophic criteria. The present practice rests solely on the assumption that *Olenellus,* using that term in the broad old sense, is confined to lower Cambrian deposits. But is it?

I do not know how the question should be answered in the case of the

Great Basin sequence, but, assuming the competence of the diastrophic evidence relied on, the answer in the Appalachian region must be in the negative. Briefly reviewing the diastrophic history of the Appalachian Valley during the Cambrian, we note first that most of the lower Cambrian areas were confined to narrow troughs which now form much of the eastern or southeastern highland border of the Appalachian Valley tract. At times these or intervening seas occupied large parts of the valley itself. Although the deposits of this epoch occur at intervals in the folded belt from Alabama to Newfoundland, it seems highly improbable that a continuous seaway extending throughout the length of this belt existed at any time in geologic history. In my opinion, it seems more in accord with known facts to regard the Appalachian trough as having been broken up—during the lower Cambrian as in later periods—into subordinate basins, each with one or more independent connections with the Atlantic basins to the east. It is thought unlikely, further, that all of these subbasins were submerged at the same time. Under this conception, the Newfoundland and New Brunswick part or parts of the trough were occupied during the lower Cambrian by waters distinct in their oceanic connections and in part or wholly different in age from the waters which at other times during the epoch laid down the lower Cambrian quartzose sandstones, shales, and limestones in Vermont and eastern New York, and the similar deposits which extend with occasional interruptions from New Jersey to Alabama. The last long stretch, doubtless, was at times divided into two or more structurally distinct parts, the Maryland and Tennessee basins (see pages 562 to 569), at least having been, even in that early period, in existence. Periodic surface oscillation occasioned alternate submergence and emergence of one and then another of these subbasins, deposition in each, therefore, being interrupted at times varying from place to place and being resumed at similarly varying times.

The close of the lower Cambrian and the beginning of the middle Cambrian is set at a time when east-west crustal shortening caused general and probably long continued emergence and, following this, resubmergence with shifting of the areas subjected to sea invasion. Except locally in the southern part of the Appalachian Valley tract the new seas spread farther westward but failed, perhaps in a corresponding degree, to extend as far eastward as the preceding lower Cambrian waters. They differed, also very notably in that the area between the Harrisburg axis in Pennsylvania and Saint Lawrence River remained emerged, while to the southward from the named axis on to Alabama the submergence of the new trough seems to have been geographically continuous and

fairly uniform. Moreover, torsion of the land mass lying to the southeast of the Appalachian Valley belt of folding is suggested by the fact that middle Cambrian troughs containing *Paradoxides* were developed in New England. The character of the movements and the probable cause of this torsion could be readily explained, but lacking space this discussion must be deferred.

Middle Cambrian deposits in the Appalachian Valley.—The deposits in southeastern Pennsylvania referred to the middle Cambrian begin with the red and purple shales and calcareous sandstone of the Waynesboro formation, in all about 1,000 feet thick, and end with the limestone and shales of the Elbrook formation, which is about 3,000 feet thick. The section has been recently described by Stose in the Mercersburg-Chambersburg folio. The Waynesboro is, in part at least, the equivalent of H. D. Campbell's Buena Vista shale in central Virginia, of M. R. Campbell's Russel formation in southwestern Virginia, and of Keith's Watauga shale in northeastern Tennessee. The Rome formation of Tennessee, Georgia, and Alabama likewise is believed to correspond in general with the Waynesboro, Russel, Buena Vista, and Watauga formations. The latter two formations may include older beds than are to be found in the Rome. Further, the middle part of the Montevallo in Alabama, perhaps the upper and lower parts as well, is correlated with the Rome. The upper part of the Montevallo possibly includes beds representing the Rutledge limestone in Tennessee, the lower part of the Honaker limestone in Tennessee and southwestern Virginia, the lower part of the Natural Bridge limestone in central Virginia, and the Elbrook formation in Pennsylvania and Maryland. The basal part, on the other hand, may locally include representatives of the Apison shale and Beaver limestone.

The time relations of these Appalachian formations to the typical Acadian deposits in New Brunswick and Newfoundland have not been accurately determined. The Protolenus zone in the latter is probably older than the Rome, but not necessarily lower Cambrian. The Paradoxides zones, also, I regard as older than the Elbrook and Rutledge. Indeed, it would not surprise me if they proved older than the Rome, though at present inclined to place them in the same stage as the Rome.

It remains to be said of the Rome that certain, perhaps but locally developed, fossiliferous beds which have been referred to the upper Rome on none too sharply defined lithologic grounds may, in fact, belong to the upper Cambrian. The fossils in these beds are chiefly of species found in the Conasauga above them in the same areas and also in the Rogersville and Nolichucky shales in northeastern Tennessee. On the

other hand, the very different fauna regarded as typical of the Rome seems to be confined to the middle and lower parts of the formation. There was much oscillation and, consequently, irregularity in distribution and local variation in character of deposits in the valley troughs during the Cambrian. When these shall have been worked out and the beds classified strictly according to diastrophic criteria, considerable modifications of prevailing views respecting the age relations of local stratigraphic facies will have been introduced. Another confidently expected result will be a more definite age assignment of provincial faunal associations. In the case of the Cambrian deposits under consideration, the revised assignment will greatly reduce the number of species now cited as common to both the middle and the upper Cambrian.

Upper Cambrian deposits in America—The Appalachian sequence.—The formations comprised in the upper Cambrian of the present work have already been mentioned in a general way, and so far as the areas covered are concerned the formations are arranged in the preceding correlation table according to their known or supposed relations to each other and to the units of the time scale. In the Tennessee basin of the Appalachian Valley, to the east of the Rome barrier, the series is defined as beginning with the Rogersville shale, the underlying unfossiliferous and not generally recognizable Rutledge limestone being for the present regarded as representing somewhat localized late middle Cambrian deposition. The Nolichucky shale forms the top of the series which thus terminates at the unconformable base of the great deposits of magnesian limestone referred to the Ozarkian system. Between the two shales lies the Marysville limestone, with a thickness varying from 200 to 700 feet. The Rogersville shale seems not to exceed 250 or 300 feet, but the Nolichucky usually attains a thickness of over 450 feet and sometimes as much as 750 feet. Both the Maryville and the Rogersville become unrecognizable southwestwardly along the strike of the rocks beyond Athens. At the same time the whole series becomes thinner, being only about 600 feet in Rogers and Spring creeks, about 10 miles west of Athens. These facts suggest that the Maryville at least laps out southwardly, and that only the Nolichucky extends uninterruptedly into Georgia and Alabama.

South of Hiwassee River and west of the Rome barrier the upper Cambrian is represented by a single formation—the Conasauga shale. Although in places apparently exceeding 1,500 feet in thickness, it is not definitely known that the Conasauga includes more than the Nolichucky, or rather that it includes deposits corresponding in age to the Maryville and Rogersville. It seems probable, however, that this is so of the rela-

tively thick sections. It may be true, especially in the southern extension of the Cahaba Valley where the Conasauga is represented by thin bedded and only moderately argillaceous limestone 1,100 feet in thickness. But I feel certain that the Conasauga never includes the Rutledge, despite the fact that it always rests on the Rome. In support of this statement, I would cite the fact noted two pages back that beds often included in the Rome where this formation is in contact with the Conasauga contain Rogersville and Nolichucky fossils. Among these are the following brachiopods determined by Walcott: *Micromitra alabamensis, Obolus lambornei, O. minimus, O. willisi, Lingulella desiderata, L. ino, L. similis, L. tarpa, Dicellomus appalachia,* and *Wimanella harlanensis*—all of which, so far as known, are confined to the upper Cambrian as here understood.

The upper Cambrian west of Mississippi River.—Eopaleozoic marine sedimentation began in Missouri with the upper Cambrian. At the base of this section is the Lamotte sandstone, an irregular deposit of detrital matter filling the hollows of the old land surface and introductory to the Bonneterre dolomite. The latter is followed, apparently, without break by the Elvins formation, which begins with a shale and ends with an earthy magnesian limestone. The last is in unconformable contact with the dolomites of the Ozarkian system. The sandstone contains *Obolus lambornei*, which passes up into the Bonneterre. Associated with it in the latter and in the calcareous shales of the Elvins are *Micromitra* sp. *Paterina* cf. *stissingensis, Obolus sinoe, Lingulella acutangula, L. similis, L. texana, Dicellomus nanus, D. politus?, Linnarsonella girtyi, Acrotreta microscopica, Billingsella coloradoensis, B. major?, Eoorthis indianola, E. remnicha texana,* and *E. wichitensis.* The articulate brachiopods seem to be confined to the lower half of the Elvins, the inarticulate species to the Bonneterre and Lamotte. The total Cambrian section in southeastern Missouri does not exceed 900 feet in thickness; and all three formations lap out of existence against the pre-Cambrian Saint Francis islands.

Except that the Bonneterre dolomite part of the section is represented by glauconitic calcareous sandstones and shales, the upper Cambrian section in the Arbuckle and Wichita Mountains of Oklahoma (Reagan formation) and in central Texas (the Katemcy) is practically the same as in Missouri. The Reagan and the Katemcy agree on the whole even better with those of the Deadwood formation in the Black Hills and Big Horn Mountains in South Dakota and Wyoming. The faunas, too, have much in common. Among these are trilobites, but only the

brachiopods have been studied sufficiently by Walcott to insure safety in comparisons. Of the 14 species of brachiopods, listed from the upper Cambrian Reagan formation in Oklahoma, and chiefly from the calcareous upper part, for which the name Honey Creek member is proposed, 8 species are found in Texas, 6 in Wyoming, 5 in Missouri, 4 in the upper Mississippi Valley, and 2 in Tennessee and Alabama. Of 19 species collected from central Texas, 7 occur in Wyoming, 7 in Missouri, 2 in the upper Mississippi Valley, and 2 in east Tennessee.

While the faunal similarities above noted are believed to be sufficient to establish the general contemporaneity of the formations in the widely separated areas mentioned, the more or less striking dissimilarities suggest impeded communication between the several areas. It is not improbable, further, that oscillation and shifting of seas occurred, with deposition going on in one place while slight emergence prevailed at another, so that none of the fossiliferous beds in certain of the areas is strictly synchronous with richly fossiliferous beds in any of the others. If oscillation of this kind obtained during the upper Cambrian we should expect to see it manifested, especially on comparing the sequence of faunas and deposits in the Appalachian and Cordilleran provinces with those in the interior continental provinces. Here in fact is where the greatest discrepancies are encountered. Comparing the interior areas with each other decided community of species is observed. It is strongest between Texas, Oklahoma, Colorado, and Wyoming, good between these and Missouri on the south and the upper Mississippi area on the north, and surprisingly weak between Missouri and the upper Mississippi localities. Evidently, there was no direct communication between the latter two areas.

Correlation of Eopaleozoic beds in the Appalachian and interior provinces with those in the Atlantic province is but seldom entirely satisfactory. The principal exceptions are those carrying graptolite faunas, which were occasionably swept into the continental troughs and basins by favorable marine currents. The Bretonian of Matthew, which is commonly referred to as upper Cambrian, contains one of these graptolite zones. This is the Dictyonema flabelliforme zone, the type species of which, together with two or three associated graptolites, is widely distributed in eastern America and western Europe. It affords a basis on which we may correlate with reasonable confidence. For reasons that will be brought out in discussing the Canadian system, the Dictyonema flebelliforme zone is regarded as post-Ozarkian, hence as much younger than the upper Cambrian as here defined. In fact, all of the Bretonian seems to me younger than the Ozarkian. On the other hand,

I agree with Walcott in seeing nothing but middle Cambrian in Matthew's Johannian (Divisions C 2 *a, b, c*), and thence down in the section to the base of the Protolenus zone. If these views are well founded, then there are neither upper Cambrian nor Ozarkian deposits in the New Brunswick sections described by Matthew.

Taxonomic relations of the lower Cambrian to the middle and upper Cambrian.—In his great work on "Paleogeography of North America," Schuchert separates the "Acadic or Middle Cambrian" as a distinct system from the "Georgic or Lower Cambrian system." The grounds for this separation are not very clear. As near as I can make them out, the fact chiefly relied on is that

> "Toward the close of the Georgic the eastern lands are known to have moved, and apparently this elevation drained the entire trough from Labrador to Alabama. This movement is of great significance in the subsequent distribution of the faunas, for it is seen that when the seas again invaded the region of this fold the descendants of the former universal Pacific Olenellus faunas were prevented from mixing with those of the northern Atlantic. On the west of this protaxis of "Middle Cambric" time were the Olenoides faunas of the Pacific realm, while to the east are the Atlantic Paradoxides biotas. Here occurred, therefore, the birth of the Appalachian protaxis of Dana and the Chilhowee-Green Mountain barrier of Ulrich and Schuchert. In the Cordilleran region the seas are continuous." (Op. cit., p. 483.)

Apparently another important part of the evidence that induced this author to divide the Cambrian into two systems is the "Saint Croix transgression . . . the duration of which embraced all the Middle Cambric and some of the Upper Cambric as generally defined." I regret that I can not accept this age assignment of the Saint Croixan. My dissent is based primarily on stratigraphic and diastrophic grounds; and certainly there is very little about the Saint Croxian fauna as developed in the Mississippi Valley and in Tennessee, Missouri, Oklahoma, and Texas that is closely comparable with the middle Cambrian faunas collected by Walcott in the Cordilleran basin, or again with the typical "Acadian" fauna of the north Atlantic province. The Saint Croixan transgression succeeded the deposition of thousands of feet of middle Cambrian beds, and, as stated a few pages back, the diastrophic and sedimentary record of this transgression makes an admirable closing epoch for the Cambrian period.

Regarding the diastrophic movements which separated the middle Cambrian from the lower Cambrian, they are no more important than those which preceded the upper Cambrian. Indeed, movements, similar in kind and order of magnitude, took place two or more times in each

of the Paleozoic periods. The "birth of the Appalachian protaxis" surely did not occur at the close of the lower Cambrian, for it was in evidence long before, having formed the eastern shore of the lower Cambrian trough, at least to the south of New York. It may be true that the Chilhowee-Green Mountain barrier of Ulrich and Schuchert is first clearly indicated at this time; but this barrier can not possibly be the Appalachian protaxis. It lies to the west of that axis, and the date of its origin is still undetermined. In my opinion, the Chilhowee axis existed as a low ridge in pre-Cambrian times and that it formed the western border of the lower Cambrian trough just as the Rome barrier at times, especially in the Ordovician, limited the westward expansion of Atlantic waters in east Tennessee. (See table, page 544.) Further, I believe that the Rome barrier, and certain other axes to the west of it, were in rudimentary existence, if not in pre-Cambrian times, then at least during the middle Cambrian. However, our inquiry in the case of these old warps concerns itself less with the date of their origin than with the determination of the age when they first gave lodgment to a Paleozoic sea.

As I see it, the principal geographic difference between the lower and middle Cambrian in the middle and southern thirds of the Appalachian Valley region is that, whereas the older continental seas were largely confined to a trough lying to the east of an old axis over which remnants of the lower Cambrian Chilhowee rocks are now piled by westward thrusting, the middle Cambrian seas were mostly—perhaps entirely—developed in the narrow crumpled area between the Chilhowee barrier on the east and the Powell barrier (between the Newman and Clinton troughs) on the west. Except that other relatively subordinate parallel axes were developed in the meantime, the Cambrian shifting of the seas in the Appalachian region was essentially similar to the east-west shifting that took place, as described in Part II, so frequently in the same region during the Ordovician.

If the differences between the lower and middle Cambrian seas were of sufficient importance to justify the systemic separation of the two series, then the upper Cambrian would be entitled to similar distinction. Then, too, the Ozarkian would embrace two, or perhaps three, systems, the Canadian two, the Ordovician at least four, and the Silurian three or four. The free entrance of Atlantic waters into the Appalachian troughs and their exclusion during some preceding or succeeding stage or epoch is a very unsafe criterion on which to base systemic distinctions. It is well worth consideration in discriminating groups and series or stages and epochs, but a geologic period spans a longer time interval in

which a rhythmically related suite of diastrophic events and consequent sea shiftings occurred.

The inadequacy of the evidence adduced by Schuchert in making two distinct systems of the "Georgic" and the "Acadic," and especially the inconsistency of his practice, will be best shown by comparing this case with an almost identical later case in which at least equally clear evidence was ignored. I refer, namely, to the relations of the Chazyan, particularly the late Chazyan Blount group, of the Ordovician in the Appalachian Valley to the succeeding Mohawkian series. For the purpose of this comparison the Blount group, which comprises the Normanskill graptolite zone and other formations with Atlantic faunas, may be said to correspond closely in geographic distribution and distinctness of faunas with the lower Cambrian, while the succeeding Mohawkian may be compared with the middle Cambrian. If anything, the distinctions which Schuchert conceives to be of systemic importance in the older case are even more conspicuous in the younger instance. And similar movements, though in reversed order, occurred at the close of the Stones River. But who would think of dividing the Ordovician into a Stones River system, a Blount system, and a Mohawkian system? It is true Schuchert separates the post-Mohawkian part of the Ordovician and places it, together with the Richmondian, into a "Cincinnatic system," but this involves somewhat different considerations that will be discussed in their proper place.

OZARKIAN PERIOD OR SYSTEM

Definition of the term.—Under the term Ozarkian system I include all the formations in the Appalachian Valley that can be shown to be younger than (1) the top of the upper Cambrian Nolichucky shale in northeastern Tennessee and (2) the top of the Conasauga shale in southeastern Tennessee, northwestern Georgia, and northeastern Alabama and which are older than the base of the Stonehenge limestone of the Canadian system in southern and central Pennsylvania. Wherever I have seen the contact with the underlying upper Cambrian shale or shaly limestone evidence of interrupted sedimentation was noted. This is true even in those cases in which gradual transition is suggested either by increasing development of limestone upward in the Nolichucky or by interbedding of thin layers of shale with relatively pure and more highly magnesian limestone in the basal part of the Knox. Something of both conditions was observed in the vicinity of Morristown, Tennessee, and the latter condition is seen in Chestnut Ridge south of Sneedville. At other places the boundary is sharp and clear, with shale beneath and

either dolomite or magnesian limestone above. The top of the system also is everywhere in unconformable relations to succeeding deposits.

The most convincing part of the evidence on which it is claimed that an important stratigraphic hiatus separates the upper Cambrian in the southern half of the valley from the overlying Ozarkian lies in the greatly varying age of the beds forming the base of the latter in different localities. Occasionally, as in River Ridge, 3 miles northwest of Morristown, Tennessee, the Copper Ridge chert rests on the Nolichucky. More commonly the Knox begins with an older division 300 to 700 feet thick, while in the vicinity of Montevallo, Alabama, three still older formations, aggragating at a maximum something near 2,500 feet of dolomite, intervene between the base of the typical Knox and the top of the Conasauga. The hiatus between the two systems, therefore, represents locally in east Tennessee over 3,000 feet of known calcareous deposits laid down elsewhere in Tennessee and in central Alabama. Even this great thickness of lower Ozarkian deposits does not fully measure the time break, for a gap is still indicated between the Briarfield dolomite at the base of the new system and the top of the upper Cambrian.

On account of the oscillatory nature of the continental surface a complete and accessible sedimentary record of any geologic period is an impossibility; and the Ozarkian is no exception to the rule. In one section the lower part is well developed, while either the middle or upper, or both, parts may be poorly represented; in another section the basal part is absent, while the middle series may be very fully developed; in a third section an upper series may be present that is wanting in the other exposures. The sequence so far as known, then, is made up of more or less disconnected but commonly interlapping parts whose stratigraphic relations are determined according to the faunal and physical criteria and correlation principles discussed in Part II of this work. The typical exposures occur in the Ozark region of Missouri. Though much thinner than the Appalachian record, the Missouri section makes a more satisfactory type because here the rocks are more fossiliferous and the stratigraphic sequence, in an epitomized way, more complete.

Derivation of the name and the type section.—For reasons mentioned the term Ozarkian, a modification and restriction of the name "Ozark series," suggested by Broadhead some years ago,[85] seems highly appropriate. Broadhead was the first to use the geographic name Ozark as a stratigraphic term; hence it was preoccupied in geological nomen-

[85] American Geologist, vol. viii, 1891, p. 33.

clature when Hershey several years later proposed "Ozarkian" for a post-Pliocene period of erosion.

Broadhead's Ozark series, as described by him, embraced all the beds in the Ozark uplift in Missouri between the pre-Cambrian complex in the Saint Francois Mountains and the top of the Joachim limestone (First Magnesian limestone of Swallow). Like Swallow before him, he believed the base of the "Fourth Magnesian limestone" to be, if anything, a little older than the Lamotte sandstone. Recent investigations prove this opinion in error, but it is unnecessary to point out the details. It will suffice to state that Swallow's Fourth Magnesian is younger than the Potosi dolomite—which constitutes the base of the Ozarkian system in Missouri—and of course younger than the Elvins, Bonneterre, and Lamotte, which together constitute the upper Cambrian as developed on the flanks of the Saint Francois Mountains. Broadhead's definition of the Ozark series is further modified by elimination of the two upper members—the "First Magnesian" and the Saint Peter sandstone—which belong at the base of the second system above the Ozarkian, namely, to the Ordovician. Broadhead did not know that a great system of rocks is developed in the Appalachian region—indeed, it is scantily represented even in southern Missouri and better in the adjoining State of Arkansas—between the Saint Peter and the Jefferson City dolomite ("Second Magnesian limestone"). In Missouri, then, the Ozarkian comprises all beds younger than the Elvins and older than the base of the Canadian system represented in north Arkansas by the Yellville dolomite.

A detailed description of the Ozarkian formations in Missouri will not be attempted here. Preliminary descriptions were published by Bain and Ulrich,[86] and more recently by Buckley.[87] The latter makes such additions to the section and changes in nomenclature as had become desirable in the meantime. The sequence and grouping of the Eopaleozoic formations given by Buckley (op. cit., pages 15, 19) is essentially as in my correlation table, except that he draws the Cambro-Ozarkian boundary at the top of the "Central Marble bed," while I have finally decided that it should be drawn at the important unconformity between the Elvins and the Potosi.

A full description of the formations, faunas, and geologic history of the Ozark uplift being in course of preparation, the following brief notes on the formations of the typical Ozarkian section may be sufficient for present purposes.

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[86] Bull. U. S. Geological Survey, No. 267, 1905, pp. 26-35.

[87] Missouri Bureau Geology and Mines, vol. ix, pt. 1, 1909, pp. 51-62.

Potosi dolomite.—This is the oldest of the Ozarkian formations in Missouri. It is a light gray to dark bluish gray, rather massive dolomite, the surface of the rock weathering hackly and many of the beds with drusy quartz masses, seams, and incrustations. Surfaces underlain by this formation exhibit abundant masses of cavernous banded calcedony and drusy quartz inclosed in a stiff deep red residual clay. This drusy quartz is very characteristic of the formation. Maximum thickness, 300 feet or more; well exposed in Washington and Saint Francois counties, especially in the vicinity of Potosi. Fossils exceedingly rare and poorly preserved. So far but two specimens have been seen, one an undeterminable gastropod about one inch in height, the other a fragment of Cryptozoon.

This is not the Potosi group of Bain and Ulrich, who used the term under a misapprehension of the wishes of the then State geologist of Missouri, but the Potosi formation of Buckley, which is entirely satisfactory.

Eminence chert.—This is the proposed name of a very cherty dolomite that rests, apparently unconformably, on the Potosi or overlaps that formation and then usually comes into contact with the pre-Cambrian porphyry. Above it is limited by the base of the Proctor dolomite, the interval between the top and bottom being not less than 200 feet in Shannon County. The Eminence is widely distributed in Missouri, being especially well displayed in the valleys of Carter and Reynolds counties, which adjoin Shannon on the east. It comes to the surface also in some of the deep valleys near the Osage, in the northern part of Camden and the southern part of Morgan counties. Though of varying kinds, a large proportion of the chert of this formation is white and dense and much of it is fossiliferous. Many species have been collected and most of them are well marked and characteristic of the formation. They comprise several large species of umbilicated Holopea-like gastropods, which, having a deeply notched outer lip, I am referring to a new genus—*Sinuopea*. *Holopea sweeti* Whitfield is a congeneric species. Another of the more striking gastropods is a large trochoid shell which also belongs to an undescribed genus. Among the cephalopods are three species reminding of *Piloceras* and one or two of *Cyrtocerina*. Associated with the mollusks are a few trilobites—*Dikellocephalus* and *Illænurus*—the latter apparently being confined to the Eminence in Missouri.

Characteristic species of the Eminence fauna have been found at a number of localities in Alabama and Tennessee and near Lexington, Virginia, in the lower part of the Copper Ridge division of the Knox; also in the lower part of the Oneota dolomite in the upper Mississippi Valley

and at Beauharnois, near Montreal, Canada. Judging from these occurrences, the Ozarkian continental seas attained their maximum distribution at this time.

Proctor dolomite.—This is the third formation of the system as developed in Missouri. The formation is easily recognized by its non-siliceous, massive beds, the absence of chert at this horizon causing it to stand out conspicuously between the two profusely cherty formations which sharply define it above and beneath. The formation is best developed in Morgan and Miller counties, where it attains a thickness of about 60 feet. In Shannon and Carter counties it is much thinner and seems to be absent locally altogether. As usual with non-cherty dolomites, fossils, if not wholly absent, are at least very scarce in the Proctor.

Gasconade formation.—This formation (Buckley; middle part only of Gasconade of Bain and Ulrich) is the next above the Proctor. Like the Gasconade, it is easily distinguished in Miller and adjoining counties, where it attains a thickness of approximately 265 feet, and consists almost entirely of profusely cherty dolomite. In these counties the base of the formation is formed by a sandstone—the "Third sandstone" of Swallow, the Gunther of Buckley—which rests unconformably on the otherwise very different Proctor. The top also is not difficult to find here, being overlain by the sandstones and conglomerates of the Roubidoux. However, on the eastern and southern sides of the Ozarkian area, neither the Gasconade nor the Proctor is conspicuously developed, so that, in the absence of fossils, it is sometimes difficult to distinguish this formation from the Eminence, or even to decide whether it is present at all. In the latter regions again the Roubidoux is not typically developed. Possibly it is absent; or, if present, it grades upward into the Jefferson City. The upper boundary of the Gasconade also may therefore be obscure locally. Still, to any one knowing the fossils and able to find them, satisfactory separations are readily possible, for the three faunas (Eminence, Gasconade, and Roubidoux-Jefferson City) are very different.

The Gasconade fauna is a large one, but not altogether new. Indeed, it is a few species of this fauna that Hall in 1847 and Cleland in 1903 described from the chert beds at the top of the Little Falls dolomite at Little Falls, New York. Among these New York fossils is *Helicotoma* (*Euomphalus*) *uniangulata*, the most distinctive and best of the Gasconade guide fossils. So far as I can make them out, all the other species described by Hall and Cleland from the chert at Little Falls occur also in Missouri. Several species of this fauna have been found near Whitehall, New York, and four, in part the same species, a few miles

south of Roaring Spring, Pennsylvania. Apparently it occurs also in Iowa. Finally, a very good representation of the Gasconade fauna has been collected from the Chepultepec chert in the vicinity of Chepultepec, Alabama. Evidently this sea was nearly as large as the preceding Eminence submergence.

Roubidoux formation.—It is 70 to perhaps 225 feet in thickness, and succeeds the Gasconade. Probably a considerable hiatus separates the two. In some places at least evident unconformity exists; in others the break is not very clearly indicated. The formation consists of alternating beds of sandstone, quartzite, conglomeratic and oolitic chert, massive chert, dolomite, and shale, all exceedingly variable in thickness and areal extent. The thinner sandstones are often ripple-marked and suncracked. The proportion of clastic matter in the Roubidoux is greater in the northwestern half of the Ozarkian area than in the southeastern, but the siliceous components—in the form of sandstone and chert—are everywhere abundant. The cherts look much like those in the Gasconade, and were it not for the beds of sandstone and conglomerate associated with them it would often be practically impossible to distinguish the two formations. Fossils are very rare in the Roubidoux, and none that could be determined were collected.

Jefferson City dolomite.—The Roubidoux seems to be merely the introductory stage of this formation which is the last of the Ozarkian formations in Missouri. It consists mainly of two kinds of dolomite, the fine-grained, argillaceous, earthy-textured, relatively soft, white to buff or gray form known as "cotton rock," and the more massive, medium-grained variety weathering hackly on the surface. The two are interbedded with each other and with thinner beds of sandstone, shale, and more or less chert. A large part of the chert is in the form of silicified masses of *Cryptozoon minnesotensis*, which species is characteristic of the formation in Missouri and usually very common. Other fossils are rare, especially in the middle and lower portions. In thickness the formation varies from less than 100 to 200 feet in the eastern and southern parts. This variation may be largely due to Paleozoic erosion. At any rate, the formation seems to be thickest in northern Arkansas, where it is locally overlain by the Yellville formation of the Canadian system. The contact with this Canadian formation is almost as clearly unconformable as when some later Ordovician to Pennsylvanian deposit rests on it.

At many places in Missouri and Arkansas, but so far as known only on the southern and western sides of the uplift, very fossiliferous cherty beds are found overlying the Cryptozoon-bearing typical Jefferson City. At two or three localities evidence of unconformable relations between

the two was satisfactorily indicated, but as most of the occurrences are of merely the residual mantle following deep surface decay of the original magnesian limestone beds, the contact between them is seldom seen. Chert conglomerate is frequently found at this horizon, and at several localities unstratified accumulations of brownish, red, and green clays were associated with the conglomerate pebbles. At other places the presumably basal agglomerate has been silicified into rough masses of chert. Most of the occurrences, finally, are confined to old downwarps, which probably formed small embayments of the shoreline at this and subsequent times.

In the early part of my investigation of the Ozark uplift this overlying bed was assumed to be a locally fossiliferous upper bed of the Jefferson City dolomite. With the progress of the work this interpretation became more and more improbable and is now abandoned. The true significance of the fauna finally became clear when comparisons proved its general identity with early to middle Canadian faunas found in the lower part of the Yellville in northern Arkansas, beneath the middle of the Arbuckle limestone in Oklahoma and in approximately corresponding deposits in central and western Texas, in the Wells Creek uplift of central Tennessee, at many points in the Appalachian Valley from Tennessee to Pennsylvania, in the Champlain Valley, and in Newfoundland. The most characteristic fossils of this widely distributed series of Canadian deposits are the horn-shaped opercula, for which the generic name *Ceratopea* is later on proposed. Six or seven distinguishable species of these opercula are now known, but the shells to which they belonged have not been preserved. The associated gastropods and cephalopods, of which some twenty species have been collected in Missouri, are closely allied to and in part the same as Beekmantown limestone fossils described from New York and Canada by Whitfield and Billings.

The Ozarkian in the southern Appalachian Valley.—As developed in central Alabama and east Tennessee, the Ozarkian sequence, beginning below and passing upward, comprises the following formations:

Briarfield dolomite (new).—It is 1,250 feet thick, well exposed in Cahaba Valley along Six-Mile Creek, 10 miles southwest of Montevallo, Alabama. Not observed elsewhere. Section studied in 1910 by Charles Butts, whose notes have been generously placed at my disposal. According to his observations, the Briarfield follows about 1,100 feet of thin-bedded amorphous blue limestone, with earthy streaks on weathered surface. Fossils procured from finely granular limestone at the base of this underlying formation indicate its age as upper Cambrian. Contact with the base of the Briarfield, though not fully exposed, apparently sharply defined.

The Briarfield consists chiefly of medium thick-bedded blue and gray siliceous dolomite. On weathering the basal part is marked by abundant dense residual chert. Except for this the lower half of the formation is without chert. Through some 400 to 500 feet of thickness above the middle the weathered rock is streaked with convoluted plates of silica and weathers cavernous with drusy incrustations. This is followed by about 200 feet of blue dolomite, which forms the top of the Briarfield as provisionally drawn. The last is followed by 275 feet of typical Ketona dolomite. The only fossils observed are of *Cryptozoon* cf. *proliferum*, of which a well developed reef, consisting of coalescing individuals 3 to 24 inches in diameter, occurs about 400 feet above the base of the formation.

Ketona dolomite.—It is well developed in Birmingham and Cahaba valleys in Alabama, but elsewhere unknown. Recently described by Butts as a basal member of the Knox dolomite. Thickness variable, commonly 300 to 400 feet, with a maximum development of 800 feet or more, as observed by Butts in the Cahaba Valley about 5 miles north of Montevallo. As noted above, this thickness decreases to 275 feet at Six-Mile, some 12 miles south in the same valley. The Ketona consists almost entirely of gray dolomite which is nearly pure and especially noteworthy because of the small percentage of silica contained in it. Apparently unfossiliferous. Succeeded by the Potosi, the lower Knox, or the Copper Ridge.

Potosi (?) dolomite.—A formation that forms the basal division of the Ozarkian in Missouri, and is so closely simulated by deposits found in the Cahaba Valley of Alabama that a distinct name seems unjustifiable. So far as known, the Potosi is entirely absent in the Appalachian Valley to the west and north of a point in the Cahaba Valley about 5 miles north of Montevallo, where, according to unpublished observations by Charles Butts, it wedges in between the typical Knox and the Ketona. The maximum development of the Potosi in the Cahaba Valley is estimated by Mr. Butts at something like 500 feet. Near the bridge over Six-Mile Creek, at Six-Mile, it seems to be only about 275 feet. The rock is a blue or bluish gray fine-grained dolomite, notably siliceous and cavernous. On weathering the surface of the ground is covered with large and small masses of cavernous drusy-surfaced quartz, which also incrusts the weathered surface of the outcropping beds. Except that it is more abundant, this residual material recalls the middle to upper part of the Briarfield dolomite. In the Cahaba Valley the Potosi is succeeded directly by the Copper Ridge cherts of the Knox proper. No fossils of any kind have been seen here in the Potosi. They are exceedingly rare also in the supposed equivalent beds in Missouri.

Basal division of the Knox dolomite (s. st.).—Rather generally in east Tennessee and southwest Virginia grayish dolomite and limestone, practically free of chert, constitute the lower part of the Knox proper. So far as known, this lower division, which I formerly thought to represent the Ketona, but now believe to be a younger and quite distinct formation, does not occur on the west side of Murphrees Valley, Alabama, nor has it been recognized in Cahaba Valley. Even in the Tennessee basin it varies considerably in thickness, possibly being absent altogether locally, as in River Ridge north of Morristown, while in other places it seems to exceed 600 or 700 feet. The latter figure is attained between Clinchport and Speers Ferry, Virginia. The formation, which for the present remains unnamed, was recognized at Knoxville; hence it is a part of the typical Knox dolomite of Safford. In Tennessee and southwestern Virginia, where the Briarfield, Ketona, and Potosi formations have not been detected, the Knox rests on upper Cambrian formations, either the Nolichucky or the Conasauga shale. When present the lower member of the Knox is readily distinguished by its more calcareous and much thicker beds. Most of its beds are magnesian, but few, if any, are dolomite. Many, on the other hand, contain so little magnesia that they may justly be called limestone. The latter are fine-grained and not infrequently contain more or less shaly layers. Chert is very sparingly developed, not only in the unweathered rock, but also in the residual clays of the surface. The practical absence or scarcity of chert and the presence of nearly pure and often shaly limestone distinguishes this lower member of the Knox from the profusely cherty main mass of the formation which overlies it and for which the name Copper Ridge chert is proposed.

Copper Ridge chert (new).—Of the three divisions commonly recognizable in the Knox, the highly cherty ridge-making middle division is the most persistent and by far the greatest. This middle division, for which the term Copper Ridge chert is here proposed, is readily distinguished from the lower and upper divisions by the hard white or gray chert which is developed by segregation and liberated under the slow process of subaerial decomposition of the dolomitic matrix. The resistant character and finally great abundance of this chert almost invariably gives rise to broad and long ridges, among which that known as Copper Ridge, in northeast Tennessee, is the excellent example chosen to supply the name and type of the member or formation.

As a formation the Copper Ridge chert is best displayed, and probably also best developed, in the middle and western parts of the Appalachian Valley in Tennessee and Alabama. Here its average thickness is nearly

2,000 feet, and it rarely falls under 1,200 feet, except along the Rome barrier, where, as between Birmingham and Gadsden, it was greatly reduced locally by pre-Ordovician erosion. The maximum thickness observed is in Chestnut Ridge south of Sneedville, Tennessee. Here, deducting some 600 to 700 feet apparently repeated by faulting, an estimate based on dip and width of outcrop indicated a thickness of about 2,800 feet. Both the lower and upper members of the Knox are relatively thin in Chestnut Ridge, the former being 360 feet, the latter only about 200 feet.

The road from Beans Station to Evans Ferry, on Clinch River (see Morristown quadrangle), follows Indian Creek, where it cuts through Copper Ridge. A fine section is shown here, practically every foot of the Knox being laid bare. Beginning on the northwest side, the section begins with the upper 80 feet of the Rutledge limestone and continues unbrokenly through 170 feet of Rogersville shale, 360 feet of Maryville limestone, 650 feet of Nolichucky, 345 feet of lower Knox, 1,345 feet of Copper Ridge dolomite (little chert is shown in the freshly cut rock), 100 feet of dove-colored low magnesian limestone—the lower half cherty—and 470 feet of light-colored dolomite and magnesian limestone, constituting, together with the preceding 100 feet, the upper Knox. The last is succeeded by the Mosheim limestone, and on through Lee Valley to the top of Clinch Mountain by an excellent section of the Ordovician as developed in the west Knoxville trough.

Fossils are rare in the Knox. Excluding *Cryptozoon,* I have never seen any in either the lower or the upper member and all told only a drawer full or so of prepared specimens out of the Copper Ridge chert. So far as the collections go, they indicate at least two fossiliferous horizons, both apparently near the middle of the Copper Ridge formation. Aside from this, their stratigraphic relations are unknown. One contains *Syntrophia campbelli* and fragments of so-called Cambrian trilobites, the other gastropods and cephalopods found in the Eminence formation of Missouri. The same or a close ally of the *Syntrophia,* also trilobites of very similar character to those associated with it in Tennessee, are found in Shannon County, Missouri, in the same formation (Eminence) *above* the gastropods. If these faunal occurrences are trustworthy indications of one and the same stratigraphic zone, then a considerable hiatus is suggested in the Missouri section between the Eminence and Potosi formations.

Several forms of *Cryptozoon* are found in the Copper Ridge. Two of them have a broad stratigraphic significance, one, forming hemispheric masses and provisionally identified as *C. minnesotense*, being confined to the upper part of the chert formation; the other, a compound form ap-

parently indistinguishable from *C. proliferum*, of the Saratogan in New York, being common only in the lower and middle parts. A third form—ledgelike, loosely lamellar in structure, and with mammelons about 2 inches in diameter—is most frequently seen about the middle and may be confined to this part.

Upper division of the Knox.—In east Tennessee and southwestern Virginia to the west of the Athens shale trough, the Copper Ridge chert is usually overlain by a third member of the Knox. Along the lines of the principal barriers it is often absent, presumably having been removed by erosion during the Canadian period. Usually this upper division begins with 100 feet or so of fine-grained, dove-colored, nearly pure or but slightly magnesian limestone, the lower part of which sometimes contains a considerable amount of chert. Above this, from 400 to nearly 1,200 feet of fine-grained, mostly yellowish or very light bluish gray magnesian limestone may be found before reaching the base of the Ordovician. Very little of it could with any justice be called a dolomite, much of it is argillaceous and laminar, and many layers fairly pure limestone. Some of the beds are massive, others weather shaly. The latter not infrequently are highly colored or mottled with purple and green. As a rule, chert is not a conspicuous feature of areas underlain by these rocks.

Although the lower boundary may not always be drawn at precisely the same horizon, there is certainly little difficulty in distinguishing this lithologically variable upper formation as a whole from the more uniformly dolomitic and much more cherty Copper Ridge formation. There are, however, two grave difficulties in the way of determining the exact age of the upper Knox. In the first place, aside from a few *Cryptozoon minnesotense* ? observed in the faulted Knox band west of Dry Branch, Virginia, the upper member has so far proven entirely unfossiliferous. The second difficulty is that there are two evidently distinct formations with either of which it may finally be correlated. The first of these is the Roubidoux-Jefferson City division of the Ozarkian in Missouri. The second is the 2,000 feet of slightly magnesian and sparingly cherty limestone which is fairly well displayed at Jonesboro, Tennessee, and extends northeasterly into Virginia. The latter rests on unquestionable Nolichucky and has always been described as a lithologically modified representative of the Knox dolomite. However, in a recent visit to Jonesboro, fossils were procured at several horizons down to within 400 feet of the base of the limestone, which make it reasonably certain that the whole mass is younger than the Knox and probably of Canadian age. Prior to this discovery I was inclined to correlate the Jonesboro limestone with the upper Knox, but according to the evidence now in hand it is thought

preferable to place the latter in the Ozarkian.[88] This conclusion is of considerable consequence, since it means that the Jonesboro area was emerged throughout the Ozarkian period. It means, further, that the Canadian seas failed to cover most of the valley of east Tennessee to the west and southwest of Jonesboro.

Regarding the relations of the upper Knox to the Jefferson City dolomite, the evidence is not altogether conclusive. It will be noticed that the upper Knox is placed beneath the Chepultepec formation and that this is correlated—the fossil evidence is very satisfactory on this point—with the Gasconade of the Missouri section. This arrangement is based on two facts: First, that the physical break between the Copper Ridge and the upper Knox is not as sharply defined as it should be if a long time had intervened between them; second, that in Murphrees and Cahaba valleys, in Alabama, the only localities in the southern Appalachian region in which the Chepultepec is yet known, the topography indicates a relatively non-resistant zone between the Chepultepec and the Copper Ridge that in all probability corresponds to the upper Knox in Tennessee and Virginia.

The Chepultepec chert formation (new).—The western part of Chert Ridge, in Murphrees Valley, Alabama, just west of the old town of Chepultepec (see northeastern angle of Birmingham quadrangle), is made by a formation that seems to be but seldom included in the Eopaleozoic sequence of the Appalachian Valley. So far as known, it represents the last of Ozarkian deposits in this province. Chepultepec is located in a narrow depression or irregular valley that, as noted in the preceding paragraph, probably represents the "upper Knox" of this work. This narrow valley extends an unknown distance northeastward from Chepultepec. Southward from the town where its width is sufficient to include about 300 feet of beds, it is traceable about 3 miles. Beyond this point the beds which are responsible for its existence apparently wedge out. Further on in the latter direction Gravelly Ridge, which may be described as a continuation of Chert Ridge, seems, moreover, to consist only of the Copper Ridge division of the Knox.

Through the observed extent of the valley-making band of supposed upper Knox the ridge to the east is composed of the underlying Copper Ridge Knox. To the west is another highly cherty formation that is the subject of these paragraphs and for which the new term Chepultepec formation is proposed. Fossils are relatively common in the new formation

[88] In accord with this older view, R. S. Bassler, in his report on "The Cement Resources of Virginia" (Virginia Geological Survey, Bull. No. II-A, 1909, pp. 151-157), refers these upper Knox beds to the Beekmantown.

and unquestionably of younger types than have been found in the Copper Ridge. The distinctness and superposition of the Chepultepec with respect to the three divisions comprised in the typical Knox of Tennessee may thus be set down as reasonably established on both stratigraphic and faunal grounds. All this evidence is repeated in the Cahaba Valley sections.

The section at the type locality begins in Murphrees Valley at Chepultepec Station, which is located on the Conasauga formation, and passes upward through about 300 feet of non-cherty dolomite referred to the Ketona by Butts, then through approximately 1,700 feet of Copper Ridge cherty dolomites, then 300 to 400 feet of concealed beds thought to be "upper Knox," followed by about 1,000 feet of cherty magnesian limestone—the Chepultepec formation—and unconformably over this by Stones River limestone, which occupies the valley between Chert Ridge and West Red Mountain.

Like the Copper Ridge, the Chepultepec limestone seldom outcrops. Both formations are recognized chiefly by the residual chert which accumulates on the surface of the ground with the progress of subaerial decay. On close comparison the cherts of the two formations proved to be readily distinguishable by persistent differences. By far the most of the Copper Ridge chert is white to gray, hard, and of a dense texture, sometimes approaching flint. Occasional layers are oolitic. The Chepultepec chert, on the other hand, is never flinty, but always relatively soft and more or less mealy in texture, and when resistant to the hammer it is because of toughness rather than hardness. Moreover, especially in the upper 300 feet, much of the chert is drusy and the masses containing the drusy plates and cavities are soft, wormy, and stained red.

Fossils are very rare in the lower part of the formation, but are fairly common and in considerable variety in the upper 300 feet. About 20 species have been collected from this zone in the vicinity of Chepultepec. The fauna being mostly undescribed, it can not be listed in a satisfactory manner. Perhaps it will suffice to say that it includes *Archeocyathus* ?, *Scenella*, *Helicotoma uniangulatum* (Hall), *Holopea ? turgida* Hall, *Sinuopea sweeti* (? Whitfield), three Liospira-like shells, another resembling *Murchisonia putilla* Sardeson, *Piloceras newton-winchelli* Ruedemann, *Cameroceras*, and *Orthoceras*.

At least ten of the Chepultepec species occur in the Gasconade formation in Missouri, four in a cherty dolomite near Roaring Spring, Pennsylvania; three or more in the chert at the top of the Little Falls dolomite at Little Falls, New York, and three others in the same formation

near Whitehall, New York. Finally, not less than six of the species found at Chepultepec have been identified in collections from the upper part of the Oneota dolomite in Wisconsin, Iowa, and Minnesota. From these occurrences it appears that the Gasconade-Chepultepec faunal zone, though only locally developed, is yet widely distributed in America, and perhaps the most easily identifiable of the Ozarkian horizons.

The Ozarkian in the upper Mississippi Valley.—In the upper part of the Mississippi Valley the Ozarkian includes four long established formations, namely, (1) the Mendota dolomite, (2) the Jordan sandstone (Madison sandstone of Wisconsin), (3) the Oneota dolomite, and (4) the Shakopee dolomite, the last including the New Richmond sandstone, which is thought to indicate an introductory clastic phase of the Shakopee rather than a distinct formation. The Mendota dolomite is commonly identified with the Saint Lawrence limestone of Minnesota, but I am not convinced that this relation is a fact. Unfortunately I have had no sufficient opportunity to study this problem in the field; and the fossils from beds between the Dresbach below and the Oneota above now in my hands are far from satisfactory in kind, number, and exact stratigraphic assignment. The few labeled Mendota limestone suggest no other than species found in the Eminence formation in Missouri. On the other hand, the only time I saw beds on the west side of the Mississippi occupying the position and supposed to be of Saint Lawrence age, namely, at Lansing, Iowa, I satisfied myself that their lower part at least represents some portion of the Elvins in Missouri, and hence is of late Cambrian age. At present, then, it seems not improbable that the upper Mississippi Valley sections include two thin formations, distinct in age and geographic distribution, between the Dresbach and the Jordan.

Regarding the age of the Oneota we know certainly only this, that its upper part contains a considerable and quite unquestionable Gasconade fauna. It is therefore older than the Roubidoux and possibly all Gasconade. But the collections in the National Museum include other small lots of fossils marked as coming from the "Lower Magnesian" in Wisconsin (especially Eikey's quarry, near Baraboo) and Minnesota that seem to be older and probably of the age of the Eminence. If these really belong in the Oneota, then the Jordan sandstone and the Mendota limestone may both be older than the Eminence. This possibility, which in fact I regard as very remote, has nevertheless influenced the tentative arrangement of these formations in the correlation table. Whatever the final arrangement may be, it seems certain now that the Ozarkian will be

found to be less fully and probably somewhat differently represented in the upper Mississippi area than it is in the Ozark region.

The Shakopee fauna is a well defined association, and although much remains to be done in the way of critical comparisons, sufficient progress has been made to show that its like is found in Missouri only *above* the Roubidoux. Possibly the top of the Shakopee, as now understood, locally includes a Canadian fauna. This is suggested by certain species described by Sardeson which remind strongly of forms in the Beekmantown in New York and in the Yellville in Arkansas and Missouri. However, taken as a whole, the nearest parallel of the Shakopee known occurs in the Jefferson City dolomite. For the present, then, it seems safe to correlate the New Richmond sandstone and the Shakopee of Minnesota, Iowa, and Wisconsin with the Roubidoux and Jefferson City formations in Missouri.

The Ozarkian in other parts of North America—In the Arbuckle and Wichita uplifts in Oklahoma.—If Ozarkian deposits occur in south central Oklahoma, they are included in the lower half of the great Arbuckle limestone. The upper half, at least, of the 5,000 to 6,000 feet of limestone and dolomite comprising this so-called formation is undoubtedly younger than the top of the Ozarkian in Missouri, and probably no less certainly older than the base of the Saint Peter. It falls, therefore, within the geological interval that it is intended to cover by the term Canadian. Just how much, if any, of the lower half of the Arbuckle is to be assigned to the Ozarkian can not be decided without reexamination of the deposits in the field. The whole formation may prove to be Canadian. On the other hand, the upper and lower parts of the basal 700 feet or so contain trilobites that may well be upper Cambrian; and between these trilobite beds lies about 400 feet of pink and white marble interbedded with massive cream-colored, black-weathering dolomite that of the whole section is the most likely to be of Ozarkian age. More probably, however, this 700 feet basal division is to be correlated with the Elvins of Missouri, which would make it late upper Cambrian. Next follows a 2,000 feet series of massive interbedded pure and magnesian limestone in which not a sign of organic remains was seen. This great mass may be either Ozarkian or Canadian. However, since it is lithologically like the succeeding 2,300 feet, which was arbitrarily marked off at the first appearance of fossils—a species of one of the Canadian types of *Maclurea*—I incline to the latter view. The overlying 1,000 feet or more, which is thin-bedded to shaly and frequently fossiliferous, is, like the preceding 2,300 feet, all unquestionable Canadian.

The facts are essentially the same in the western or Wichita uplift. Resting on the Reagan, the Arbuckle begins with beds holding the same possibly late upper Cambrian trilobites mentioned as occurring at the base of the formation in the Arbuckle uplift, and the next faunal zone is undoubtedly Canadian.

Judging from the facts in hand, it seems unlikely that the Ozarkian period is extensively represented in Oklahoma. Even the small inlier of old cherty rocks, which comes to the surface in a structural dome cut through by Spavinaw Creek, near the eastern border of the State, and in which I at first thought I recognized a late Jefferson City fauna, proves on closer examination to contain nothing but Canadian fossils.

In central Texas.—The Eopaleozoic section in central Texas begins with an upper Cambrian section that is in every respect comparable with the deposits of the same epoch in south-central and southwestern Oklahoma. This agreement seems to pertain also to the overlying dolomite and limestone, this part of the section being, so far as it goes, practically the same as the Arbuckle limestone in Oklahoma. The limestone series is much thinner than in the Arbuckle Mountains section in Oklahoma, the upper 3,000 feet of the Arbuckle limestone as developed there being unrepresented; but in thickness, lithologic features, and beds represented the Texas section agrees very well with the section shown in the Wichita Mountains uplift. The dolomitic "marble" bed, which, with accompanying thinner limestones carrying trilobites, constitutes the basal division of the Arbuckle limestone in Oklahoma, was clearly recognized in the vicinity of Marble Falls, in Burnet County. This part of the section may be Ozarkian, but neither the trilobites nor the lithologic character and sequence of the beds suggests any established Ozarkian formation with which it might be correlated. Provisionally it seems advisable to place these beds as late upper Cambrian.

Following the "marble" series, but locally apparently overlapping it, so that it comes into contact with the Honey Creek member of the Reagan, are magnesian and relatively pure, fine-grained, and more or less cherty limestones that are most certainly of Canadian age. This conclusion, as will be shown later on, is based on unequivocal fossil evidence. According to present evidence, then, it appears that the section in central Texas, the same as the Arbuckle and Wichita mountains sections in Oklahoma, contains no positively recognizable Ozarkian deposits. The same is to be said of the Franklin mountains sections in western Texas.

The Ozarkian in western North America.—Ozarkian deposits seem to be wanting entirely on the eastern side of the Rocky Mountains province.

Formations of this age are probably included in the "Upper Cambrian" and "Ordovician" parts of the House Range and other sections on the west side of the Rockies between Utah and British Columbia published by Walcott, but I hesitate to point them out. I have, however, more definite information concerning the presence of Ozarkian deposits in the Seward peninsula of Alaska. Here Collier, and subsequently Kindle, in studying the Port Clarence limestone—a formation of great thickness and variety of contents, having early Ozarkian or perhaps late upper Cambrian beds in its lower part, Canadian in the middle, and Richmondian deposits at the top—collected *Cryptozoon* and a brachiopod of the genus *Finkelnburgia* that is indistinguishable from one found in the Gasconade formation in Missouri.

Ozarkian formations in New York and New Jersey.—The Ozarkian is represented in New York by the Potsdam sandstone, the Theresa passage beds, the Hoyt limestone, and the Little Falls dolomite. The essential parts of the evidence on which the typical Saratogan is removed to this system are given in the preceding discussion of the Cambrian. A fuller discussion of the organic and physical evidence has already been published in a paper on the Little Falls dolomite and associated formations in New York by Ulrich and Cushing. For details of the stratigraphy the reader is referred to this paper.[89] Concerning the age of the Little Falls, the only additional comment that is of sufficient importance to be inserted here is that the fossiliferous cherts at the top of the formation at Little Falls may prove to be separated from the underlying dolomitic mass by another hiatus. If this could be established I would correlate the dolomite beneath the hiatus with only the lower part of the Copper Ridge division of the Knox and not with the whole of that great southern Appalachian formation as it now appears in the accompanying Eopaleozoic correlation table.

In New Jersey the Ozarkian is represented by the greater, generally thick-bedded, lower part of the Kittatinny formation. The Ozarkian age of the bulk of this magnesian limestone, with an estimated thickness, according to Kümmel and Weller, of 2,500 feet or more, is clearly indi-

[89] Two typographical errors in the paper by these authors (New York State Mus. Bull. 140) should be corrected here. On line 10, page 134, a table is mentioned by error as on page 129. The table really referred to is a broader correlation chart that was inadvertently omitted by the printer. The second is on page 131, where the word *thin* in the seventh line from the bottom should read *thick*. The last sentence of the middle paragraph on page 130 does not express what it was intended to say. It should be modified so that line 8 from the bottom of the page will read: sea is *well* represented *only* in *parts of* the southern Appalachian Valley and certainly,—the changed and added words being italicized.

cated by the fossils collected at Newton, Blairstown, and Carpentersville and described in the State report by Weller. Locally, thinner-bedded limestones are found at the top of the Kittatinny, but the contact of these with the underlying dolomites has not been observed in New Jersey. However, as these upper beds contain an unmistakable Canadian fauna, there is probably an unconformity here between the two the same as in Pennsylvania and New York, where a well defined stratigraphic break separates similar Ozarkian and Canadian deposits. The Canadian beds referred by Kümmel and Weller to their Kittatinny limestone being, according to report, only locally developed in the Kittatinny Valley, and when present doubtless readily enough distinguished, it seems desirable to restrict the use of the term to the Ozarkian part of the section. In that event the Canadian part should be called Tribes Hill limestone, for it is evidently the southward extension of that recently named New York formation.

The Ozarkian in Pennsylvania—Kittatinny formation (Allentown limestone).—In a brief account of papers read at the Second Annual Spring Conference of the Geologists of the Northeastern United States, published in "Science" September 24, 1909, I note that Edgar T. Wherry proposes the name Allentown limestone with the following laconic characterization: "Upper Cambrian, white to gray, dolomitic, largely oolitic, full of Cryptozoon, 2,000 feet." From my knowledge of the rocks at and in the vicinity of Allentown, Pennsylvania, it is evident that the new term is intended to include the rocks in the Lehigh Valley which I recognize as Ozarkian. As I had formerly intended to apply the same name to these beds I would be glad to adopt Mr. Wherry's term Allentown now if I had not come to the conclusion in the meantime that a slight and quite justifiable restriction of the New Jersey name Kittatinny limestone rendered the new name unnecessary. Used in this restricted and more definite sense, the term Kittatinny becomes a useful designation for Ozarkian deposits in New Jersey and in northeastern and central Pennsylvania, corresponding essentially in stratigraphic position to the Potsdam sandstone and Little Falls dolomite of the New York section. However, detailed geologic mapping in the areas concerned will make it necessary to subdivide the Kittatinny into two or three easily recognized members.

On account of folding it is difficult to determine the thickness of the Kittatinny in the Lehigh Valley. Apparently it is over 1,000 feet and it may be as much as 2,000 feet. The formation rests unconformably on presumably lower Cambrian sandstone, shown in Quaker Hill and

Pine Top, 2 or 3 miles north ~~south~~ of Bethlehem. Various parts of the lower half are well shown in railroad cuts and quarries in the eastern part of Allentown. The upper part is exposed to the north of this city along Lehigh River in railroad cuts, quarries, and natural outcrops to near Catasauqua.

In Lehigh Valley the lower half or so of the formation consists of mainly fine-grained, often oolitic, generally not highly magnesian, massive, and thin-bedded limestones, characterized by numerous successive bands of *Cryptozoon*. The colonies of this low organism form conspicuous lenses 2 to 10 inches thick and up to 20 feet across. In section the delicate laminæ are wavy, while the upper surface is commonly thrown into mammillate elevations 1 to 2 inches from center to center. The upper half of the formation consists chiefly of massive dolomites with occasional thin beds of quartzose sandstone and oolite. Only one species of fossil has so far been found in the upper part, namely, a *Lingulella*, seemingly indistinguishable from *L. acuminata*. Canadian limestone ("Coplay limestone" of Wherry) follows the Kittatinny in this valley.

In the central valleys of Pennsylvania, between Bellefonte on the north and Bedford on the south, the beds corresponding to the typical section of the Kittatinny differ in that the lower part contains more magnesia and the upper part more quartz sand. South of Roaring Spring, the lower 400 feet of the exposed section consists of massive gray dolomite. This is followed by about 100 feet of dark, often bluish gray limestone, usually not highly magnesian, containing trilobites of an early phase of the Dikellocephalus fauna, together with the lower Kittatinny *Cryptozoon*. The succeeding 800 to 1,000 feet, constituting the upper member of the formation, consists of thin quartzite layers interbedded with heavier ledges made up of rounded quartz grains in an easily decomposed dolomitic matrix. The sandstone member is succeeded by an unmistakable northward extension of later Ozarkian, exceedingly cherty dolomites, corresponding to late Copper Ridge and Chepultepec-Gasconade horizons in Tennessee and Alabama. These Ozarkian cherts finally are followed in the vicinity of Roaring Spring by the Canadian Nittany dolomite, which is here similarly cherty and consequently difficult to discriminate without fossils. However, an important hiatus separates the two, as is shown in part by absence of the Stonehenge which underlies the Nittany at Bellefonte.

Along the main line of the Pennsylvania Railroad between Birmingham and Shoenberger stations, the lower part of the Kittatinny, which is thrust westward here over Stones River limestone, begins with a

massive limestone, but for the most part is made up of thin-bedded, occasionally argillaceous dolomites, with an estimated thickness of about 600 feet. The following 1,000 feet or more consists of interbedded quartzite and more or less heavy-bedded gray dolomite, with occasional beds a few feet thick of thinly laminated dolomite. Thin beds of oolite, often silicified, are rather common toward the top.

In the Nittany Valley anticline, at Bellefonte, only the upper 340 feet is exposed. This consists almost entirely of fine or coarser grained, generally dark colored dolomite. A little sandstone occurs beneath the middle of the exposure, and oolitic chert is sparingly distributed through the upper two-thirds. So far as it goes, the formation agrees very well with the corresponding part in the Lehigh Valley.

The Kittatinny formation is to be correlated in a general way with the Conococheague of the Chambersburg, Pennsylvania, quadrangle. But that formation, with its clay and sand-streaked, non-dolomitic limestone, is so strikingly different in its lithologic aspects—in both fresh and weathered states—from the Kittatinny that a distinct name is desirable. The Conococheague in its typical phase (see description in U. S. Geol. Survey Folio 170) extends north in the Cumberland Valley, and thence passes on in the Lebanon Valley as far at least as Reading, being clearly recognizable to the north of that city between Ontelaunee station and the city waterworks. The distribution of these two phases of Ozarkian deposition in Pennsylvania suggests at least partially separated basins. Confluence of these basins is indicated during the early Canadian, but that separation, with some modifications, soon again prevailed is clearly suggested by faunal and lithologic differences noted in comparing the Canadian sections at Chambersburg and Bellefonte.

The Ozarkian period in Newfoundland and Europe.—The Ozarkian may be represented by divisions D and E in Logan's section of western Newfoundland, but the available information respecting these beds is far from satisfactory. Divisions F, G, and H, however, have furnished good fossils, which, as described by Billings, leave no doubt of their Canadian age.

I have failed entirely to recognize the Ozarkian in the British sections. If the system is really present there, then it must be in the "Upper Lingula Flags," since the "Lower Lingula Flags" are middle Cambrian and the Tremadoc, according to published lists of fossils, undoubtedly Canadian. The faunas ascribed to the Upper Lingula Flags, which contain *Dictyonema flabelliforme* and *Orusia lenticularis*, also impress me as younger than any American fauna now referred to

the Ozarkian. Possibly these flags, together with the overlying Tremadoc—represented on the American side by the Bretonian in New Brunswick—are intermediate in age between the top of the Ozarkian in Missouri (Jefferson City dolomite) and the base of the Canadian at Bellefonte, Pennsylvania; but for the present I prefer to regard them as Atlantic deposits, corresponding in a general way to the lower divisions of the Canadian as now recognized in America. They may be in part a little older than the Stonehenge and Tribes Hill limestones, but the higher parts probably are younger. The principle of rhythm in diastrophic movements alone seems to hold out any definite promise of a final disposition of these difficult Atlantic deposits in the geologic time scale. (See discussion of the Dictyonema zone, page 678.)

In the Swedish and Russian Baltic sections the Ozarkian is almost certainly absent. So far as known, then, the Ozarkian seems to be confined to North American areas. Schuchert's alternative use of Cambrian for Ozarkian, therefore, is as yet groundless.

CANADIAN PERIOD OR SYSTEM

Definition of the term.—To the Canadian system I refer all deposits that on the one side can be shown, or which are believed, to be younger than the last of the Jefferson City dolomite in Missouri and the Shakopee in the upper Mississippi Valley, and which on the other side are thought to be older than the first sandstone and limestone (Everton) of the Saint Peter series in northern Arkansas. In other words, the Canadian embraces the wide interval that began with the first advance of the sea following the closing withdrawal of the Ozarkian seas, and which ended with the last emergence preceding the first or Saint Peter advance of the Ordovician waters.

The truth of the belief that the Stonehenge limestone, which lies at the base of the Canadian in Pennsylvania, is younger than the highest of the formations in the Mississippi Valley referred to the Ozarkian is positively demonstrable, on the basis of superposition and horizontal continuity of sediments and faunas, only to the top of the Chepultepec or Gasconade faunal zone. However, as this zone is succeeded unconformably in the Mohawk Valley by the Tribes Hill limestone, which contains characteristic Stonehenge fossils, the remaining upper Ozarkian (Roubidoux-Jefferson City) part of the stratigraphic sequence is inserted by inference in the hiatus between the base of the Tribes Hill and the Gasconade zone at the top of the Little Falls. This is done pri-

marily by virtue of the "principle of maximum thickness of overlapping formations" (see page 554). Corroborative evidence, however, is found in north Arkansas and Missouri, where the Jefferson City dolomite is succeeded unconformably by Canadian beds containing a fauna that is found in Oklahoma nearly 4,000 feet beneath the top of the Arbuckle limestone—that is, beneath the base of the Ordovician, which begins here with the Simpson formation. The faunal evidence points to the same conclusion, the Jefferson City fossils, so far as they go, being clearly Ozarkian, while the Stonehenge-Tribes Hill fauna is as clearly Canadian, and not Ozarkian. I wish it to be understood, however, that in my opinion the upper Ozarkian formations in Missouri do not completely fill the gap between the top of the Gasconade zone in the Little Falls and the base of the Tribes Hill-Stonehenge overlap. There is a fair chance that certain deposits in the Atlantic province may finally be added to the base of the Canadian.

Regarding, also, the upper boundary of the Canadian, the bare possibility is recognized that the "Saint Peter series" may be in part the equivalent of the basal portion of the heavily developed Stones River group in the Appalachian Valley. But the Saint Peter is found in deep wells in central Kentucky beneath the Stones River. Besides, in Maryland and Pennsylvania, as frequently noted in this work, an unconformity separates the thickest Stones River from the youngest of the Canadian formations recognized in the Appalachian Valley. The Day Point Chazy likewise lies unconformably on the highest Beekmantown. It is altogether reasonable, therefore, that the Saint Peter belongs in this gap, though it probably does not fill it.

Authority for the name.—As originally defined by Dana in 1875 and as employed since by himself and other authors, the term Canadian was applied to the middle one of three divisions of the Lower Silurian. Beneath the Canadian, which included the Quebec group of Canada and the Calciferous and Chazy of New York, came the Primordial period; above it the Trenton period. The inclusion of the Chazy doubtless was induced by the supposed mixture of Calciferous and Chazy faunas in the Quebec. Indeed, as determined by Logan and Billings, the Levis graptolite fauna seems to occur in western Newfoundland above faunas that, but for this, would have passed very well for Chazy or even younger Ordovician. The Chazy fauna, too, had always been set apart from those of the "Trenton periods" as quite distinct and presumably older. Under the circumstances the Chazy could not be logically separated from a group

based primarily on rocks holding the Calciferous fauna when they were limestones and the Levis graptolites when they were shales.

In the past decade or so much has been learned concerning the fauna and stratigraphy of the Chazy. It is known that the Chazy rests unconformably on the Beekmantown and that in stratigraphic position, and to a certain extent also in faunas, its two lower divisions (Day Point and Crown Point) correspond in general to the lower and middle Stones River group of Tennessee and Kentucky and of the Appalachian Valley from Pennsylvania southward; hence that its taxonomic relations are with the succeeding formations rather than the preceding. Dana having properly referred the Stones River group of Tennessee to his "Trenton period," which corresponds very nearly to the Ordovician of the present work, his reference of the Chazy to the Canadian, when viewed in the light of recent knowledge, becomes merely an excusable error in correlation. And, as it is now practically certain that the faunal sequence in Newfoundland is confused at the critical point, either by overthrusting of Canadian black shales with Levis graptolites on much later Ordovician limestone or by some other means, the reasons for associating the Chazy with the Beekmantown "Calciferous" are entirely removed. The upper boundary of the Canadian may, therefore, be drawn beneath the Chazy without departing in any essential respect from the intention and practice of the author of the term.

But the lower boundary of the Canadian of Dana and authors generally also requires redefinition and revision. The Calciferous of twenty or more years ago, in fact up to several years after 1899, when Clarke and Schuchert[90] proposed the geographic term Beekmantown to take the place of Calciferous, is not exactly the same as it is understood to be today. The recent work of Cushing, Ruedemann, and the writer in New York has shown that rocks varying greatly in age have been referred to the Calciferous[91]; also that the typical Calciferous in the Mohawk Valley is mostly Ozarkian.

The "Calciferous" rocks of the Mississippi Valley, likewise, are nearly all Ozarkian, and the same is true of a few localities in Canada, notably 3 miles east of Beauharnois, that Billings and Logan referred to the Calciferous; but the formations in New York and Canada which furnished most of the fossils that became known as the Calciferous—now Beekmantown—fauna are of Canadian age. The Ozarkian dolomites beneath them in the Champlain Valley being almost unfossiliferous, and as the unconformity of the contact with these underlying dolomites was

[90] Science, new ser., vol. x, 1899, pp. 876-877.

[91] E. O. Ulrich and H. P. Cushing: New York State Mus. Bull. 140, 1910.

not observed, it was to be expected that the whole series of magnesian limestones in the Champlain Valley would be thrown together and correlated with the Calciferous of the Mohawk Valley. Still, despite the magnitude of the eliminations, the nucleus of the Canadian is now, as it has always been, the limestones in the Champlain-Saint Lawrence region containing the Beekmantown fauna. The elimination of the Chazyan and Ozarkian formations originally included on evidence now regarded as misinterpreted does not exceed the bounds of legitimate emendation. Such changes are demanded by progress. In the present case it is gratifying to note that they do not alter Dana's original conception of his Canadian in any really essential respect. The only change of consequence is that the term is now given a higher rank, but this also is a legitimate amendment.

The term Beekmantown limestone.—The typical Calciferous outcrops being in the Mohawk Valley, and the formation there, as said, mostly Ozarkian in age, the term Beekmantown, which is based primarily on the fossiliferous Canadian rocks of the Champlain Valley, is not, as was believed, exactly equivalent to the lithologic term Calciferous in stratigraphic nomenclature. Strictly speaking, the Beekmantown, considered as a formation, should be determined by the beds found outcropping at the locality from which the name is taken. Brainerd and Seely's Calciferous Divisions C, D, and E are represented at and in the immediate vicinity of Beekmantown. Division B possibly also comes to the surface in that neighborhood, but Division A, so far as I can learn, has not been seen there. Probably nine-tenths of the fossils regarded as characteristic of the Beekmantown come from Division D. A few of these occur in the underlying Division C, but none found in C, D, or E crosses the line into Divisions A and B. The faunal break between B and C, therefore, is complete. The unconformable stratigraphic relations between the two divisions, as observed in the vicinity of Ticonderoga, emphasizes the importance of the break. The unconformity is rendered the more apparent by overlap extinction of a fine-grained limestone which is sometimes included by Brainerd and Seely in Division B. This basal member of the Canadian seems to be entirely absent in the Fort Ticonderoga section.

The boundary between Divisions B and C being of great importance, and as the lower two beds (A and B) do not show in the typical section of the Beekmantown, it seems unwise, not to say unwarrantable, to include them with the typical members of the formation. Viewed solely from the standpoint of the lithologist, the desirability of distinguishing

Divisions A and B from the overlying beds is scarcely less manifest than it is to the paleontologist and stratigrapher. As A and B (beneath the unconformity) are strictly equivalent to the Little Falls dolomite of the Mohawk Valley, this discrimination may be said to have been carried out already. Finally, as long as we endeavor to draw formational and group boundaries in accordance with the important stages in geological history, the Ozarkian Divisions A and B should be grouped with the underlying Theresa and Potsdam. Indeed, the boundary between B and C is thought to be of such high significance that if it were decided to continue the present division of the pre-Silurian part of the Paleozoic into but two systems instead of the four here advocated the separation of the two should be at this line.

In consideration of the foregoing facts and arguments, it is proposed to restrict the Beekmantown to the three upper divisions (C, D, and E) of Brainerd and Seely's Lake Champlain Calciferous. The term is thus made to cover the whole of Canadian deposition in the Champlain trough, which here consists only of more or less magnesian or arenaceous limestones. Though divisible into good formational units which can and should be mapped separately in the Champlain Valley, the mass, as a whole, may still be referred to as the Beekmantown limestone group or series. Further, in folded areas like the Mercersburg-Chambersburg quadrangle in Pennsylvania, where cartographic limitations permitted the discrimination of only the well marked basal member (the Stonehenge), the designation of the series simply as the Beekmantown limestone seems eminently proper. As I see the matter now, this term is properly applicable throughout the Maryland basin part of the valley. But to the south, in the central Virginia, Tennessee, and Alabama basins, other names are thought desirable. In central Pennsylvania also, where the Canadian is divisible into four mappable formations, the name Beekmantown should not be used.

Type sections of the Canadian system.—The exposures which furnished the principal part of the information respecting the sediments and faunas on which the Canadian period was originally founded are in the Champlain and Saint Lawrence valleys and in northwestern Newfoundland. The first contains the calcareous facies embraced in the restricted Beekmantown limestone. The beds have been well described by Brainerd and Seely and Logan, and their faunas by Billings, Whitfield, and Ruedemann. The essential parts of this information have been well summarized by Schuchert in his recent paper on Paleogeography of North America.

The second represents the shale facies, which is typically developed in the Levis channel of Ulrich and Schuchert. Its fauna is almost totally different from that of the limestones of this period, being composed chiefly of graptolites that, with very few exceptions, are entirely wanting in the limestone facies. The graptolites are found in several zones, each of which is marked by diagnostic species. As commonly designated, these zones from below upward are as follows: (1) Dictyonema flabelliforme zone, (2) Tetragraptus zone, with two subzones—Clonograptus or lower Tetragraptus bed and Dichograptus bed—and (3) Didymograptus bifidus or Phyllograptus typus zone, which doubtless includes distinguishable subzones. Ruedemann discovered the first of these zones in a basal part of the Levis shale exposed at the falls of Hoosic River at Schaghticoke, New York. He also found and published the section in Deepkill, near Grant Hollow, Rensselaer County, New York, which includes the second and third zones besides an overlying "Diplograptus dentatus zone," which may be younger than Canadian. All of these graptolite faunas are fully described, and their stratigraphic relations discussed, by Ruedemann in papers published by the New York State Museum, notably in Memoir 7, 1905. The shale facies and the graptolite faunas are further discussed beginning page 674.

The third or Newfoundland facies consists chiefly of limestones—constituting Divisions F (500 feet), G (400 feet), and H (265 feet) of Logan's section—which contain, besides a much larger number of localized species, just about enough Beekmantown fossils (according to Billings 12 out of 62) to make it reasonably certain that these widely separated limestones are approximately contemporaneous and certainly of the same period. The general composition of this Newfoundland fauna, especially of Division G, is more closely simulated by the Canadian fauna in Oklahoma and western Texas than by any in the Beekmantown limestone.

The Beekmantown in Maryland and southeast Pennsylvania.—Two sections showing the general composition of the Beekmantown limestone in the Maryland basin of the Appalachian Valley, also provisional faunal lists, have recently been published in Folio 170, Mercersburg-Chambersburg, Pennsylvania, quadrangles, by the U. S. Geological Survey. They illustrate, also, the lithologic changes taking place in the formation in an east-west direction across the strike. In the eastern belt fully three-fourths of the 2,265 to 2,400 feet of thickness consist of nearly pure limestone; in the western band more than half of its 2,310 feet is more or less highly magnesian. However, the Stonehenge member

at the base—485 to 570 feet in the former, 530 feet in the latter—is, so far as observed, everywhere relatively non-magnesian. As for the Canadian beds above this member, they become even more magnesian in central Pennsylvania. The following generalized review of the Beekmantown in the Chambersburg belt seems desirable here:

Beginning with the base, which evidently is in unconformable relationship to the underlying Conococheague formation, there is first the Stonehenge member, consisting of 570 feet of limestone, the lower part of which is massive and dove in color, the middle and most of the upper parts generally of darker color, with contorted argillaceous and siliceous laminations, oolites, and thin bands of intraformational conglomerate. Some large, broadly umbilicated gastropods, allied to *Pleurotomaria canadensis* Billings, smaller forms of *Ophileta, Dalmanella wemplei,* and fragments of trilobites, are distributed through the middle and lower parts of the member.

The next higher division is nearly 800 feet thick. It begins with a 60-foot bed of largely oolitic, cherty limestone. This is followed by 300 feet of dove, pink, and bluish, fine-grained pure limestone, locally with chert. The division ends with 275 feet of fine-grained, nearly pure limestone, in which are occasional beds of magnesian limestone, and several layers of porous and sometimes drusy chert. Near the middle there is commonly a considerable development of pink, fine-grained marble. Except in thin zones fossils are rare in this division, the more notable forms being *Ophileta complanata, Maclurea affinis, Eccyliomphalus* cf. *triangulus,* and *Bathyurus* cf. *conicus. Cryptozoon steeli* is not uncommon in the lower 100 feet. Compared with the Bellefonte section, the Nittany dolomite seems to correspond in a general way with this division.

The third division, 200 to 250 feet thick, consists of blue and dove limestone, cherty in the upper half. At the base a 6-foot blue limestone is filled with rounded quartz grains. Fossils occur rather abundantly and sometimes in good condition. The most characteristic are *Dalmanella?* cf. *electra,* large hornlike opercula of the proposed genus *Ceratopea* (see page 665), *Liospira canadensis, Asaphus canalis, Bathyurus caudatus, Amphion salteri ?,* and *Primitia gregaria ?.* With these occur *Maclurea affinis* and *Eccyliopterus triangulus.* Judging from this faunule, this division appears to correspond very nearly with that of "Division D" of the Beekmantown in the Champlain Valley. Probably this Pennsylvania occurrence represents an earlier facies of the fauna than the one found at Fort Cassin, Vermont. The Axeman limestone in

the Bellefonte section may correlate with this division, but their respective faunas are too distinct to lend confidence to the suggested correlation.

Overlying the preceding division, with a strong chance of a slight gap in the succession, is a fourth bed with a known thickness of 375 feet. This consists of a rapidly alternating series of pure dove limestone, nearly pure gray limestones, and other gray limestones that are rather highly magnesian. Occasioned beds or streaks of fine limestone conglomerate were observed. The lower 75 feet of this division are limited above by a fossiliferous ledge containing some peculiar sandy chert. Among the fossils are *Syntrophia lateralis, Maclurea sordida,* and species of *Liospira* and *Orthoceras.* The upper 300 feet seem to be unfossiliferous.

The fifth recognizable horizon comprises about 200 feet of thin-bedded argillaceous and pure limestone, many of the beds weathering so as to appear riddled with worm borings. Numerous fossils were collected from this division, which is distinguished especially by *Maclurea oceana?, Ophileta? disjuncta, Solenospira prisca?, Hormotoma gracilens, Turritoma acrea?, Lophospira gregaria?, Trocholites internestriatus,* and *Cyrtocerina mercurius?.*

Finally, there is a sixth division, 400 feet or more in thickness, consisting, like the fourth division, of interbedded pure and magnesian limestone, all fine-grained and of light shades of gray. Small calcite geodes are common in the lower half or two-thirds, and assist materially in recognizing the bed. Many of the layers are finely laminar, and only those highly magnesian can be called thick-bedded. Near the top are sandy cherts, and above these limestone and dolomite conglomerates; finally, hard, dense, and white chert and also a granular, quartzose variety. Secondary silicification of these cherts often produces a form resembling cauliflower that is rather generally met with about this horizon. At one place (just north of Greencastle) large quartz pebbles were associated with this peculiar form of chert. The pebbles occurred in a position leaving no doubt that they formed a part of a thin conglomerate at the base of the overlying lower Stones River limestone. More commonly, probably, the secondarily silicified cherts, including the "cauliflower" variety, mark the same boundary.

In seeking to correlate the divisions of this Cumberland Valley Beekmantown section with the divisions of the formations in the Champlain Valley the criteria afforded by lithology suggest at once that the interval between the middle of the uppermost member and thence down to the lower half of the third from the top (fourth from the base) corre-

sponds to Division E. In fact, the harmony in lithologic characters between these parts of the formation in the two areas is greater than may appear from the descriptions. This correlation is borne out by the already suggested relations of the third division and the lower part of the fourth to the Fort Cassin limestone.

The Beekmantown between Carlisle and Allentown.—Tracing the Beekmantown in a northeasterly direction from Chambersburg, it is found to hold nearly the same characters and thickness, at least as far as Carlisle. Here both the Stonehenge member and the overlying cherty Cryptozoon steeli zone, constituting the lower third of the whole, are clearly recognizable. The middle divisions maintain practically the same lithologic characters as at Chambersburg, but the fossils have become much rarer. The upper beds also are recognized without difficulty, especially the fossiliferous fifth division. This locality, finally, affords another comparatively rich fossil zone in the uppermost division, comprising species so far observed only here.

Farther northeast, between Harrisburg and Lebanon, only the middle and lower parts of the formation are to be seen. The top beds may occur under the cover of Triassic sandstone, but are wanting on the exposed Beekmantown. These rocks being thrust northwestwardly over the Martinsburg shale, it is possible that such elevated parts of the Beekmantown were largely cut away by erosion prior to the deposition of the Mesozoic sandstones. In that case the upper divisions, if present originally, may have been removed.

The lower and middle divisions of the Beekmantown are still easily recognized to the north of Reading along the Pennsylvania Railroad between Ontelaunee station and Leesport. Apparently the upper divisions (third to sixth) of the Chambersburg belt were not deposited here; and the same reason probably explains their absence between Lebanon and Harrisburg.

In the Lehigh Valley of Pennsylvania the Beekmantown is represented by the same members (lower and middle) as at Leesport, but locally, as at Ironton, beds are found with the Ceratopea fauna which is found in the third division of the Beekmantown at Chambersburg, and is thought to be represented in the lower part of the Axeman limestone or the top of the Nittany dolomite in the Bellefonte section. The Ceratopea fauna occurs perhaps, in this valley, only locally at the top of the section. In a recent letter Prof. B. L. Miller and Mr. E. T. Wherry suggest the name Coplay limestone for the Beekmantown as developed in the Lehigh Valley. I am inclined to regard the proposition favorably.

At least one and probably two anticlinal axes that at various times interfered with and perhaps prohibited the free westward expansion of the Appalachian sea doubtless extended southward from the Adirondack land mass into Pennsylvania during the greater part of Canadian time. To the more easterly one of these may be ascribed the marked differences in lithologic characters of the middle and upper divisions of this great formation observed in comparing the section at Chambersburg with those to the west in the vicinity of Mercersburg. The second axis separated the Mercersburg trough from the Bellefonte basin. The broad Harrisburg axis (see page 563), which trends northwest and southeast, exerted an even more important effect on Canadian seas in that it prohibited late Beekmantown deposition in these east Pennsylvania valleys to the north of Harrisburg. Only the early Canadian Tribes Hill and the Stonehenge member or formation extends across all these barriers, this zone being as clearly recognizable in the Mohawk Valley of New York as in the eastern and central Pennsylvanian sections. The middle and upper divisions, however, vary conspicuously in lithic characters from east to west. The same barriers became even more efficient in middle Ordovician time.

Canadian deposits in central Pennsylvania.—The Canadian is developed to extraordinary thickness in Nittany and other valleys in central Pennsylvania. According to present information, the maximum thickness for the region, about 4,230 feet, occurs at Bellefonte. The section here is divisible into four formations, the two lower of which pinch out by overlap southward. Several descriptions of the section at Bellefonte, which is almost continuously exposed, have been published, the last and by far the best by Collie.[92]

I have twice visited this locality, verified Collie's measurements, and collected some of the fossils from horizons pointed out by him. Besides discovering several additional fossiliferous zones, the section has been revised and the Ozarkian beds, which rise to the surface in the axis of the great anticline, have been satisfactorily separated from the lowest of the Canadian formations. As the section at Bellefonte affords the maximum development of the Canadian system in the Appalachian region and contains a greater number of abundantly fossiliferous zones, it seems worth while to describe it in moderate detail. This is all the more desirable because the formations into which it is readily divisible have been incorporated in the time scale.

[92] G. L. Collie: Bull. Geol. Soc. America, vol. 14, 1903, pp. 410-411.

Canadian section at Bellefonte, Pennsylvania

Upper Stones River—the lower 230 feet consisting of thin, irregularly bedded, light and darker gray, sometimes dove, fine-grained pure limestone. Locally very fossiliferous. Base of Ordovicion.

Break

Bellefonte dolomite (new)

		Feet
13. Mostly argillaceous, highly magnesian limestone, compact, often laminar, easily weathering, light gray, unfossiliferous. Upper 300 feet poorly exposed	400	
12. Yellowish gray or drab, generally fine-grained and occasionally laminated dolomite, alternating with fewer ledges of comparatively dark, finely crystalline dolomite, both generally in rather even layers of medium thickness. Nodules of chert occur but not commonly except in some massive ledges 800 to 900 feet beneath the top. The cherty bed, which is well exposed at the Central Railroad of Pennsylvania depot, contains also some irregular layers in part or wholly filled with rounded quartz grains. Others show numerous fragmentary remains of trilobites and occasionally gastropods, like *Hormotoma artemesia* (Billings), but all so firmly cemented to the matrix that they can not be determined satisfactorily	1,745	
Total thickness of Bellefonte dolomite		2,145

Axeman limestone (new)

		Feet
11. Thick and thin bedded, nearly pure limestone, dark in color, frequently stained with iron oxide and ranging in texture from compact to distinctly crystalline. The fine-grained layers are often mottled with irregularly inosculating, light colored argillaceous spots. Others are oolitic limestone conglomerates. Many of the layers are abundantly fossiliferous. Small Ostracoda (suggesting *Leperditella*, *Aparchites*, and *Primitia*) and *Hormotoma gracilens* are sometimes common in the upper 50 feet. The most characteristic fossils of the formation, and especially abundant in the lower 40 feet, are *Protowarthia rossi*, *Liospira strigata*, *Maclurea affinis*, and a trilobite like *Bathyurus amplimarginatus*	158	
Total thickness of the Axeman limestone		158

Nittany dolomite (new)

	Feet
10. Massive, light gray, finely crystalline dolomite. An outcrop out of the direct line of the section, but thought to be of this bed, contained an *Eccyliopterus* like *E. triangulus* Whitfield	198
9. Alternating beds of light and dark gray, crystalline dolomite in beds of medium thickness	313
8. Gray crystalline dolomites with some chert and a little sandstone. The chert is sparingly fossiliferous, the fossils poorly preserved, those noted being slender gastropods of the type of *Hormotoma artemesia.* The chert in this bed increases rapidly in abundance in a southerly direction from Bellefonte	132
7. Mainly thick-bedded, in part probably slightly calcareous dolomite, varying in color from light to medium shades of gray, and in texture from distinctly crystalline to very compact. The latter are brittle, sometimes resembling chert, and in one such bed good molds of *Ophileta complanata* Whitfield (?Vanuxem) and *Syntrophia* cf. *lateralis* were observed. Some chert in the residual mantle which, like that of the overlying bed, grows more abundant to the south. 4 to 8 inch balls of *Cryptzoon steeli* not uncommon with the chert	624
Total thickness of Nittany dolomite[93]	1,267

Stonehenge limestone

	Feet
6. Dark gray, compact or subcrystalline, often oolitic pure limestone, mottled with light colored, slightly magnesian limestone. Highly and characteristically fossiliferous. Among the more abundant species are *Asaphus* n. sp. (near *A. canalis* (Whitfield) but shorter). *Ribeiria calcifera?*, *R. parva*, *Eccyliomphalus multiseptarius*, *Bucania tripla*?, and *Dalmanella*? *wemplei*	27
5. Light gray, mainly compact, nearly pure limestone	70
4. Magnesian limestone chiefly	40
3. Gray, nearly pure, generally rather massive limestone with occasional layers containing a small gastropod resembling *Ophileta levata* and *Holopea raymondia.* About (perhaps more than)	390
Covered, about	50
2. Beds of thin argillaceous, fine-grained limestone alternating with thicker-bedded limestones	50

[93] The thickness of the beds of this formation are as given by Collie (op. cit., p. 411), the present writer having neglected to measure them separately. Together they gave a thickness of about 1,215 feet, or about 50 feet less than the aggregate of Collie's measurements.

	Feet
1. Rather massive limestone, some ledges nearly pure, others evidently somewhat magnesian, and many with "edgewise conglomerate;" 12 feet beneath top a ledge full of the small gastropod (cf. *Ophileta levata*) noted in bed 3. Exposed opposite gate to Nittany furnace	35
Total thickness of Stonehenge limestone[94]	662
Total thickness of Canadian in the Bellefonte section about	4,232

Break

Top of Kittatinny formation, of which about 340 feet are exposed in the axis of the anticline as seen along Logan Branch of Spring Creek. The boundary between the Ozarkian and Canadian rocks is drawn at the abrupt change from the dolomites of the former to the pure (Stonehenge) limestone formation at the base of the latter. The contact is fairly well shown along the road opposite the Nittany furnace.

The above section is repeated, but not so well shown in the east limb of the anticline.

Correlated with Canadian formations in other areas an analysis of the fossil zones in the above section leads to interesting and somewhat surprising results. The lowest of the four formations is correlated with the Stonehenge member constituting the lower 400 to over 700 feet of the Beekmantown in the Chambersburg and Mercersburg, Pennsylvania, quadrangles. Good fossils are exceedingly rare in the typical outcrops of the Stonehenge near Chambersburg, but so far as collected they offer no serious objection to being placed in essential contemporaneity with those found in the lower limestone division of the Canadic at Bellefonte. An orthid like *Dalmanella wemplei* occurs, with the new *Asaphus* and small *Ophileta levata*-like gastropods, also at Chambersburg. At both Chambersburg and Mercersburg the Stonehenge consists of alternating beds of calcareo-argillaceous, slightly magnesian rock and massive, nearly pure limestone. At both localities, again, these are overlain by cherty beds, which, in turn, are succeeded by heavy-bedded limestone in the Chambersburg area. However, in the exposures of Beekmantown limestone near Mercersburg, where the Beekmantown has a total thickness of 2,370 feet, much the greater part of the formation above the 680

[94] The corresponding beds in Collie's section have an aggregate thickness of 894 feet. This estimate is I believe excessive, and possibly due to error in transcribing field notes. The second "brecciated" bed, No. 7 of his section (op. cit., p. 411), was not observed. Possibly it is the same as his No. 3.

feet of pure Stonehenge limestone consists of dolomite. The Mercersburg section, therefore, not only compares much better lithologically with the Bellefonte section than does the one of Chambersburg, but also affords a reasonable basis for the identification of the Stonehenge in the Nittany Valley.

Toward the southwest from Bellefonte the Stonehenge, and at least a large part, if not the whole, of the Nittany dolomite wedges out, so that just north of Martinsburg, Pennsylvania, the Axeman limestone, which is there easily recognized by its fossils and lithology, comes well down toward the Ozarkian boundary. The Nittany dolomite, besides being thinner, is also more cherty than at Bellefonte, so that care is required in discriminating it from the cherts of a middle Ozarkian formation—carrying Gasconade fossils near its top—with which it comes into contact south and southeast of Roaring Spring. Fortunately, the most commonly fossiliferous of the Nittany chert zones is near the base of the formation and is marked by so characteristic a fossil as *Ophileta complanata.*

Still another cherty zone has been found apparently *above* the Axeman limestone a few miles north of Martinsburg. This contains *Maclurea cf. speciosa,* large opercula of the type for which I have proposed the name "*Ceratopea*" (see page 665), *Trochonema* sp., and a lirate *Helicotoma,* or perhaps *Gyronema,* a faunule suggesting the Yellville in Arkansas and more remotely the horizon between the middle of "Division D" and the base of "Division E" in the Champlain section. If the position of this chert is correctly determined, it must belong to the Bellefonte dolomite, in which case the fossils would be a welcome addition to the scant fauna of this formation. However, it is quite possible that the zone belongs beneath the Axeman, hence in the upper part of the Nittany.

Detailed correlations between the Canadian rocks of central Pennsylvania and those of the Champlain Valley in New York and Canada seem impossible at this time. Large collections of fossils from both regions are in hand, but the material requires preparation and more careful study than has yet been given it. At present the general trend of the faunal evidence only has been determined, and while this justifies the statement that the Canadian limestones and dolomites of the two areas are in essential accord, it is yet too early to attempt correlating the successive zones. The suspicion engendered by the present aspect of the problems that a considerable hiatus, only partially filled by reef deposits at Fort Cassin, occurs between D and E in the Champlain section, is perhaps the chief reason why a delay as to details is desirable. Pend-

ing further study, it may be said that the Fort Cassin fauna seems to be represented in the Axeman limestone and in the upper part of the Nittany dolomite by *Syntrophia lateralis, Raphistoma compressum, Trochonema exile, Maclurea affinis, Bathyurus caudatus*, and *Ribeiria compressa.*

The Canadian deposits in Oklahoma—Extent and boundaries.—Eopaleozoic deposits, beginning with the upper Cambrian Reagan sandstone, are developed in great force in the Arbuckle uplift in south central Oklahoma. In part, these extend westward about the pre-Cambrian rocks in the Wichita Mountains and southward into central Texas, where they are again at the surface in Llano and adjoining counties.

Published knowledge of the section in the Arbuckle Mountains we owe chiefly to Taff[95], who in the course of his official work for the U. S. Geological Survey, mapped part of the area of this uplift in detail. My own knowledge of the stratigraphy and paleontology of the region was acquired in a rather thorough reconnaissance with Mr. Taff of the three uplifts, the Arbuckle, the Wichita, and central Texas. Parts of three seasons, 1901, 1902, and 1908, were devoted to these investigations.

The subdivisions of the Eopaleozoic section in the Arbuckle uplift, as determined and published by Taff, are based entirely on lithologic characters; and these were not by any means all taken into account. In consequence, the boundaries of the formational units were sometimes drawn very differently from where they would have been placed had faunal and diastrophic evidence been allowed to dominate the choice. This criticism applies especially to the great series of calcareous sediments comprised in the Arbuckle limestone, which, as originally described and mapped by Taff, had a total thickness of quite 6,000 feet. However, prior to the publication of the Tishomingo Folio certain thin limestones at the base, then determined as middle Cambrian, but now classed as upper Cambrian, were transferred to the underlying Reagan formation. In the present work the name Honey Creek member is applied to this transferred member.

Subdivisions of the Arbuckle limestone.—Unfortunately, in 1901 and 1902 my acquaintance with the great masses of unevenly distributed deposits that belong between the top of the true Cambrian and the base of the Saint Peter, and which are here divided into two independent systems—the Ozarkian and the Canadian—was yet greatly inferior to what it has since grown to be. The great Arbuckle limestone, like the Knox dolomite of the Appalachian Valley, seemed an indivisible mass

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[95] J. A. Taff: Tishomingo Folio, Geol. Atlas U. S. Geol. Survey, 1903.

uniting the Cambrian on the one side with the Ordovician on the other. But with advancing knowledge the difficulties have largely disappeared, and it is now not only possible but incumbent on us to subdivide some of the two comprehensive old formational units. In the case of the Arbuckle, as partly stated on page 641, it is divisible into four well defined parts, the lowest of which may be Ozarkian, but is more likely to prove late upper Cambrian. All of these four parts are further divisible into lithologic members and faunal zones.

The second of these major divisions of the Arbuckle limestone consists of about 4,300 feet of massive pure and more or less magnesian limestone. The highly magnesian beds occur chiefly in the lower 2,000 feet of this great mass of sediments. Moreover, fossils seem to be entirely absent in this lower member in the typical section of the Arbuckle, though to the west, in the limestone areas flanking the Wichita Mountains, a considerable fauna has been collected from beds apparently corresponding to this member. However, it is possible that this member is absent there and that the fossils come from some bed of the overlying member.

The remaining 2,300 feet of the second division consist mainly of fairly pure, fine-grained limestone. Fossils occur very sparingly, having been observed at only three horizons, the first at the base, the second some 1,200 feet above the first, the third about 600 feet above the second. The first and second fossil-bearing ledges contain shells of *Maclurea*-like gastropods, which show in cross-section in the face of the rock. Though specifically undeterminable, they are evidently related to the widely umbilicated, slender-whorled types, which seem to be confined to Canadian rocks. Another horizon, apparently between the first and second, afforded numerous specimens of *Ophileta complanata?;* and another, apparently near the first horizon, but probably near the second, contained *Ceratopea keithi.* The third horizon contains a species of *Eccyliopterus* related to *E. volutatus.*

The third division is 700 feet thick and characterized by relatively thin-bedded limestones and frequency of fossiliferous ledges. The upper 200 feet are all thin-bedded and in part even shaly. Occasional thin layers of chert and maybe a few inches of sandstone are seen in the lower two-thirds. Chert occurs also in the underlying heavy bedded division, but is never a conspicuous feature in the Arbuckle limestones, except where this third division forms the top of the series and is followed by massive sandstone of the Ordovician Simpson formation.

The commonest fossils of the third division are the articulate brachiopods, of which eight species have been distinguished. Two of these

belong to the new genus mentioned in the foot-note on page 669 as bearing a general resemblance to the Ordovician *Delmanella subæquata*, but differing in having a perforated deltidium like *Clitambonites*. Then there are three species of another genus—perhaps *Eostrophomena* Walcott—that probably gave rise to the *Strophomenidæ*. Next, there are two species allied to *Polytœchia*, and finally a new type of *Syntrophiidæ*. With these brachiopods, but more commonly in separate layers, are found other fossils as follows: *Ophileta* sp., *Eccyliopterus* cf. *triangulus*, *Turritoma* cf. *acrea*, *Hormotoma* cf. *anna*, very slender shells like *Murchisonia linearis* Billings, *Cameroceras* sp., *Leperditia* sp., and small ostracods suggesting *Aparchites*.

Perhaps only very locally the third division is succeeded by about 250 feet of unfossiliferous, varicolored argillaceous limestone, and this finally by a more widely but also not generally distributed bed of fairly pure though somewhat argillaceous, thin-bedded limestone, sparingly fossiliferous, and reaching a maximum thickness of 400 to 500 feet. Together these two beds constitute the fourth or uppermost division of the Arbuckle limestone—at the same time also of the Canadian—in central Oklahoma. It is followed by sandstones, shales, and limestones of the Simpson formation, but the exact contact, which probably is unconformable by overlap, has not been observed.

As said, fossils are rather rare in the upper member of the fourth division. Near the top Mr. Chester A. Reeds found a bed containing good examples of *Didymograptus*, one of the two forms being identical with the British species recently described by Elles and Wood as *Didymograptus artus*. This graptolite horizon possibly is in the basal Simpson, which formation doubtless extends farther down in the time scale than the base of the Chazyan. Provisionally, however, it is included in the upper Arbuckle. Its age, accordingly, would be late Canadian.

Compared with the typical sections in the Canadian in the northern Appalachian, Champlan, and Saint Lawrence Valleys, the faunas in the Arbuckle limestone in Oklahoma indicate that we have here an unusually well developed sequence of Canadian deposits. The presence of *Ophileta complanata* near the middle of the 4,300-foot second division suggests that from this zone on upward the Arbuckle limestone is not older than the top of Brainerd and Seely's Division C in the Champlain section. The underlying, unfossiliferous lower member of the middle division, even though 2,000 feet in thickness, may then correspond to their Division C, plus the older Tribes Hill-Stonehenge limestone which is at the

base of the Canadian sections in New York and Pennsylvania. If these suggestions are well founded, then the Canadian part of the Arbuckle limestone will include all of the divisions of this enormous thickness of deposits, except the first, which, as stated, is most probably late upper Cambrian in age. In other words, the Canadian would be represented in the Arbuckle Mountain section by over 5,000 feet of limestone.

Eopaleozoic section in the Wichita Mountain uplift.—No complete continuous section of the Arbuckle limestone in the hills about the Wichita Mountains has been seen. It is questionable that such a section can be made there, since the rocks of this age are disturbed by faulting, and the continuity of the outcrops is broken by overlying younger deposits. Still, the presence of the Reagan formation, of the first and second divisions of the Arbuckle limestone (the latter incompletely developed), and of the Viola limestone, has been clearly established in that region. The two upper members of the Arbuckle and the whole of the Simpson seem to be wanting. So far as observed, the identified Eopaleozoic formations in the Wichita area are practically the same lithologically as in the Arbuckle area. They agree also faunally, except that the beds corresponding in position to the lower half of the main division of the Arbuckle are more fossiliferous. Most of the fossils from this zone so far determined are either the same as or closely allied to species found in the Yellville of Arkansas and the Phillipsburg limestone in Canada. Provisionally determined, this fauna includes two lithistid sponges, *Stromatocerium?* sp. undet., *Dalmanella?* cf. *wemplei, Ophileta* cf. *complanata, Eccyliopterus* sp., *Helicotoma* ? (with strong peripheral and weaker median row of nodes on upper side of whorls), *Raphistomina* sp., *Euconia ramsayi, Hormotoma* cf. *artemesia, Turritoma acrea?, Gyronema* sp., *Ceratopea* cf. *keithi, C.* sp. (slender, non-carinate opercula), and *Bathyurus amplimarginatus.*

Guide fossils of the Ceratopea zone.—Of the foregoing list of fossils the *Bathyurus*, the *Helicotoma ?*, and the two *Ceratopea* have been of the greatest service in determining the age of formations in America to be Canadian. So far as known, they are confined to, and therefore diagnostic of, a broad zone, comprising approximately the 2,000 feet of sediments following the basal 1,000 feet of the composite Canadian sequence as now understood. Though a time of considerable local oscillation, the zone as a whole doubtless represents the widest submergences that obtained during the Canadian period. In this respect, as also in its time relations to preceding and succeeding stages of the period, it is comparable to the Eminence age in the Ozarkian, the

Mohawkian epoch in the Ordovician, the Niagaran in the Silurian, and the Onondaga-Hamilton stage in the Devonian.

The *Helicotoma ?* is one of three closely related species or varieties of an undescribed type of gastropods, related on one side to *Helicotoma,* on the other to *Liospira,* but with sufficient characters of its own to justify the erection of a new genus. The shell is low, conical or discoid in shape, 20 to 40 mm. in diameter, broadly umbilicated, and narrow-whorled. The upper surface of the whorls is marked with two rows of nodes, one on the peripheral band, the other between this and the suture. A similar row of nodes is found on the under side. One of the species is very common in the fauna just listed. The same variety is associated with a larger species in one of the beds of the Yellville formation. The latter is very common at many localities in southern Missouri, and being easily recognized makes an excellent guide fossil. Both forms occur also in central and western Texas. A third variety is found, sometimes with either of the others, in the upper part of the Canadian limestone (hitherto referred to the Knox) between Bristol and Wytheville, Virginia. It has been seen also in the Lehigh Valley in Pennsylvania. At most of these localities these neat shells are associated with one or more of the *Ceratopea* and the *Bathyurus.*

The name *Ceratopea* has been used by me during the past five or six years to designate a peculiar type of operculum supposed to belong to some gastropod allied to *Maclurea.* The spiral shell itself is unknown, but as the opercula are striking and often very abundant fossils, and have great value as guide fossils, a distinctive name is desirable. Several distinct forms of these opercula are known. Two of them were figured many years ago by Billings in his Paleozoic Fossils, volume 1, page 243, figures 228 and 230. At least five others are represented in the collections in the U. S. National Museum. To make these fossils of greater use in discussions and correlations of Canadian deposits, the generic name *Ceratopea* is now formally proposed for them. As genotype, I have selected the species figured by Bassler without description in Bulletin No. II-A, Virginia Geological Survey, 1909, plate 20, figure 3. The specific name *keithi* is here applied to the genotype, Mr. Arthur Keith, of the U. S. Geological Survey, having collected at Trundles Crossroads east of Knoxville, Tennessee, some of the best specimens seen.

It is a curved variety of *Ceratopea keithi* that occurs so abundantly in the lower middle part of the Arbuckle limestone in the Wichita uplift of southwestern Oklahoma. The same variety is also a common fossil in central Texas. In both localities, as also in central Alabama, it is associated with a fourth species of the genus differing from *C. keithi*—

which is relatively short and blunt and carinated on the outer, more convex side—by its more slender form and absence of the carina. The latter is very common in a highly fossiliferous member of the Yellville formation at Smithville, Arkansas. The curved variety of *C. keithi* is found also at several localities in Christian County, Missouri, and at other points farther east in that State to Lutesville. Finally, I have it from the Cumberland and Lehigh valleys in Pennsylvania. In all cases this and the other species of *Ceratopea* occur in limestones and dolomites which had been determined as Canadian before the stratigraphic significance of these fossil opercula had been ascertained.

Canadian limestones in central and western Texas.—The Cambrian section in central and western Texas is in all respects the same as in Oklahoma. In both States there is a basal sandstone, followed by a limy and shaly zone well speckled with glauconite and a more calcareous zone—the Honey Creek member—above that. These three zones constitute the upper Cmbrian Reagan or Katemcy formation. Above this come beds corresponding to the basal division of the Arbuckle limestone. This consists of thin-bedded pure limestone and more massive dolomite and marble, and is essentially the same in central and possibly also in western Texas as in Oklahoma. The last may be of Ozarkian age, but it is thought more likely that it will prove to be late upper Cambrian. This finally is succeeded by more or less cherty Canadian limestone.

The Canadian part of the section in central Texas was not carefully discriminated from the underlying dolomites and limestones. It may be wanting locally. In other places it is less than 100 feet, while its maximum thickness in San Saba, Llano, and Burnet counties seems not to exceed 300 or 400 feet. At that it covers considerable areas in these counties, providing, as is believed to be the case, all the cherty Eopaleozoic limestones are of this period. It is succeeded by either early Pennsylvanian limestone or Cretaceous deposits.

The fauna of these Canadian beds has been collected at only two or three points, and even at these no determined effort was made to procure it. Perhaps fossils are rare and unequally distributed, but where noted the chert and limestone was filled with organic remains. The species so far collected—about 15 in number—are in every case also represented in the particular facies of the Yellville fauna found at Lutesville, Missouri. At both localities the commonest fossils are *Ceratopea keithi* (curved variety), *Bathyurus amplimarginatus,* and the *Heliocotoma?* usually associated with the first.

Judging from excellent collections of fossils in the National Museum,

there should be a fair development of Canadian limestones in the Franklin Mountains of western Texas. The greater part of the collections is from the Ceratopea zone, which here contains all the common species, besides several not observed elsewhere. A second fossiliferous zone, presumably a little lower in the section, compares species for species very closely with a fossiliferous bed holding this relation to the Ceratopea zone in the Wichita mountain section in southwestern Oklahoma. One or two sponges, probably of the genus *Calathium*, stand out prominently in the collections.

The Canadian rocks in northern Arkansas and southern Missouri—Yellville formation.—Canadian deposits found on the southern flanks of Ozarkia present some exceedingly intricate stratigraphic and paleogeographic problems. Although much evidence has been collected, satisfactory discussion is not yet possible. The following account, therefore, is confined to only the more important data in hand:

The Yellville limestone is provisionally regarded as embracing all the rocks in northern Arkansas between the top of the Ozarkian Jefferson City dolomite and the base of the Everton limestone.[96] As thus limited the Yellville is bounded both above and below by an important unconformity and comprises all the Canadian deposits on the flanks of Ozarkia. As the formation was laid down only in large or smaller embayments of the shore of Ozarkia, it follows that between the embayments these unconformities merge into one. The lower unconformity was entirely unknown when I began work in this region nine years ago, and it was not clearly established and its value appreciated till 1905. Obviously, it is desirable to revisit many localities worked prior to the latter date before the relations of certain fossiliferous zones to the Ozarko-Canadian boundary are positively determined.

As represented in northern Arkansas and southern Missouri, the Yellville formation is exceedingly irregular in distribution and variable in composition. In thickness it ranges from 0 to perhaps 250 feet. As a rule, the maximum development in the embayments is less than 150 feet. Within the formation occur lines more or less clearly indicating oscillation and interrupted deposition. The member now believed to be the lowest is known only from Lawrence County, Arkansas, at Black Rock and three to five miles northwest of Smithville, where some 40 feet of it are exposed. At the latter locality it consists of white, bluish

[96] This is in fact a restriction, but as I take it a permissible one, since Adams, the author of the term (U. S. Geological Survey, Prof. Paper 24, 1904, p. 18) had a very inadequate and in certain respects an erroneous conception of the series of rocks to which he proposed to apply it.

gray, fine grained dolomite and contains the only known occurrence of the Phyllograptus fauna in American interior rocks. With the graptolites, of which the following have been determined, *Phyllograptus illicifolius, P. angustifolius, Didymograptus bifidus,* and *D. amplus,* occur two possibly undescribed orthoid brachiopods (related to *Dalmanella wemplei*) and fragments of two trilobites, one an *Asaphus* akin to *A. canalis.* Over this comes first a 6 foot bed filled with drusy and solid hard chert containing numerous fossils, among them *Plethospira cassina, Subulites obesus,* and *Eurystomites kellogi,* all of which were described from the Cassin limestone of the Champlain Valley. It is probably this bed that is developed to a thickness of nearly 20 feet in the valley of Swan Creek, in Christian County, Missouri, and from which a well preserved fauna of more than 20 species has been collected. Near Smithville it is followed by a 1 to 4 foot bed of gray, crystalline, magnesian limestone, containing the slender noncarinate form of the opercula for which the new generic name *Ceratopea* is proposed on page 665. At other points in the vicinity of Smithville this bed either expands to 10 and even 20 feet, or another thin bed of limestone succeeds it. The latter is filled with a large and well preserved molluscan fauna. The fossils occur silicified in porous chert or free in the residual clay. Some of them are identical with well known Cassin species, while others seem closely allied to species occurring locally at the top of the Shakopee in Minnesota and Wisconsin, and to others found in the middle part of the Arbuckle limestone in Oklahoma. This bed is usually succeeded in Lawrence County by a secondarily silicified chert conglomerate, a few inches to several feet thick, and this by loose quartz sand probably derived from a decomposed calcareous sandstone referable to the Everton. Locally, however, as in the quarry at Black Rock, the hiatus at the top of the Ceratopea bed is partially represented by about 40 feet of pure and argillaceous limestone, most of it filled with undescribed sponges and bryozoa. The fauna includes also brachiopods, of types found in preceding beds, and graptolites like *Dendrograptus flexuosus* and a small variety of *Didymograptus bifidus.* But the mollusks which are so conspicuous in the underlying members are almost entirely absent.

Nearly everywhere in northern Arkansas and southern Missouri the upper part of the Jefferson City dolomite, the top formation of the Ozarkian, contains the hemispherical colonies of *Cryptozoon minnesotense* in abundance. This excellent guide fossil, therefore, has proved of great service in locating the boundary between the Jefferson City and Yellville formations and hence between the two systems—Ozarkian and

Canadian.[97] Commonly, the contact is marked by chert conglomerate secondarily silicified into solid, irregular masses. At other places it is marked by great sand reefs, against which succeeding Yellville deposits lap until finally they are covered. Such contact phenomena are best developed west of Harrison, Arkansas.

In the vicinity of Yellville the formation which has been named from this town begins with a conglomeratic bed of chert. Locally, as at several points along the railroad from 1 to 3 miles east of North Yellville, this basal conglomerate is succeeded by a few (1 to 20) feet of fossiliferous sandy porous chert. The fossils and the kind of chert agree closely with the Yellville in the Wells Creek basin of Tennessee, and with the upper part of the Ceratopea bed in Lawrence County. So far as developed the fauna of this bed (at Yellville) includes two species of *Turritoma*, *Coelocaulus* sp., *Hormotoma* sp. (cf. *Murchisonia argylensis* Sard.), *Helicotoma* sp. (cf. *H. peccatonica* Sard.), *Protocycloceras lamarcki*, *Cyrtoceras confertissimum*, *Isochilina seelyi?*, and an orthoid (*?Dalmanella wemplei*) resembling *Dalmanella subaequata*, but having an apically perforated deltidium.[98]

The bulk of the Yellville, and the part usually seen where the formation is present, succeeds the porous basal cherts described in the preceding paragraph. As a rule this part of the formation consists mainly of 50 to 120 feet of noncherty, light colored, very fine grained, argillaceous, often shaly, magnesian limestone or dolomite. The successive layers overlapped the shores of the embayments so that the upper ones are more widely distributed than the lower ones. In the mass two layers are usually distinguishable. The upper of the two is the more persistent. It occurs from 35 to nearly 50 feet beneath the sandy base of the Everton or of whatever later formation that happens to rest on it.[99] Usually it is a 2 or 3 foot bed of gray dolomite, containing drusy cavities and rough fossiliferous chert. When it forms the top surface of a hill the whole

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[97] *Cryptozoon* was observed but a single time in the Yellville, namely, along the White River a few miles west of Mundell, Arkansas. But this occurrence was of a very different species the masses—2 to 4 feet in diameter—being distinctly mammilated on the surface, the superposition of the ½ to 1 inch waves imparting a columnar appearance to weathered vertical sections contrasting strongly with the simple concentric structure of the Jefferson City species.

[98] Brachiopods of this type are highly characteristic of the Canadian period. Apparently all of the Beekmantown and Levis species that have been in recent years referred to *Dalmanella* are provided with a deltidium; hence they are at least generically distinct from that Ordovician and later genus.

[99] At many localities the Everton rests on the Yellville, at others it may be the Saint Peter, or the Izard, or the Chattanooga: or it may be that the first formation to cover it is the Saint Joe.

layer is sometimes silicified, the residual blocks being exceedingly rough and cavernous or spongy. The fossils have not been all worked out, but most of those so far studied are of exceeding interest because of their bearing on correlations. Thus among them are *Maclurea* cf. *matutina, Liospira canadensis, Hormotoma artemesia* (very large form), *Camero-ceras* cf. *brainerdi, Protocycloceras lamarcki, Cyrtoceras confertissimum?, Tarphyceras* cf. *seelyi* and *clarkei, Bolbocephalus seelyi?, Bathyurus* cf. *conicus* and *nero, Dalmanella? electra,* and *Syntrophia* cf. *lateralis* and *palmata.*

The second conspicuous layer or zone, when present, occurs from 35 to 40 feet beneath the upper. It also is often a gray pitted dolomite, but frequently it is arenaceous and sometimes the corresponding horizon is made up of irregularly interbedded sandstone, quartzite, conglomerate, and chert, aggregating as much as 6 to 10 feet in thickness. No fossils have been observed in this bed. Neither have any been seen in the argillaceous dolomite above, beneath, and between these two layers.

The fossils mentioned in the foregoing paragraphs as occurring in the various zones of the Yellville, with the exception of the highest—sponge and Bryozoa zone in the Black Rock section—and the lowest or *Phyllograptus* bed, are so clearly indicative of the Division D or Fort Cassin fauna in the Lake Champlain Beekmantown that the general contemporaneity of these Yellville and middle Beekmantown zones seems undeniable. As to the sponge and bryozoan bed at Black Rock, this may very well represent a time corresponding to some part of Division E of the Champlain section.

Age of the Phyllograptus and Tetragraptus faunas.—The discovery of diagnostic graptolites of the Phyllograptus illicifolius zone in the basal member of the Yellville formation proves it older than the Cassin fauna. Beyond this, however, and aside from the fact that it is positively younger than the last of the Ozarkian, the age of this almost universally distributed graptolite zone is yet somewhat indefinite. According to other lines of evidence, which will be discussed presently, the Levis graptolite zones, beginning with the Dictyonema flabelliforme zone and including at least the Phyllograptus illicifolius zone, correspond to the whole or parts of the interval between the middle of Division D and the top of Division B of Brainerd and Seely's Champlain Valley section. That this view extends the base of the Levis as far down the column as the lowest Canadian in the Bellefonte, Pennsylvania, section seems not unlikely; but the point can not be decided positively with the evidence now available. According to this evidence we may go only so far as to say that

the Tetragraptus zone is not younger than the Nittany dolomite, and that it may be older.

Canadian deposits in the Wells Creek basin of Tennessee.—In the Wells Creek basin, in northwestern middle Tennessee, named and briefly described by Safford,[100] the low dome-like elevation at the center of the small but sharply defined uplift is formed by a highly cherty magnesian limestone of Canadian age, but undetermined thickness. The prevailing type of the chert, which strews the surface and with a deep residual clay covers the light gray, fine grained, magnesian limestone from which it is derived, is porous—even spongy—rather soft and sandy under the hammer, and red or brown in color. With these occur harder, nearly white blocks. This cherty magnesian limestone is overlain—not, as one might naturally suppose, by some Stones River limestone, but by Lowville limestone. Owing to concealing cover at the critical point, the contact was not observed. The Lowville as usual closely resembles the Lebanon, and had hitherto been mistaken for that Stones River formation. But the discovery of *Tetradium cellulosum* and other reliable Lowville fossils enables us to correct a misapprehension and at the same time to establish an interesting and unexpected hiatus.

Some of the chert is highly fossiliferous. Slender gastropods of the genera *Hormotoma* and *Coelocaulus* are especially abundant. Other genera of the same class, like *Ophileta* (cf. *O. levata*), *Helicotoma*, and *Holopea* are also represented. Then there is a small *Orthoceras*, like *O. primogenium*, a *Protocycloceras*, a slender *Salterella?*, *Cameroceras* sp., *Cyrtoceras cf. confertissimum*, *Maclurea emmonsi?*, an Orthoid like *O. electra*, a striated *Syntrophia*, and an *Isochilina* resembling *I. armata* of the Lowville.

The general aspect of the fauna (more than half of the species are identical) is decidedly like that found in the upper part of the Ceratopea bed of the Yellville formation in northern Arkansas. As there is further notable agreement in lithologic characters, I have no hesitancy in correlating the two horizons. As a distinct name for this cherty zone of the Canadian rocks in the Mississippi Valley is desirable, especially in Tennessee, the name Wells chert is here proposed.

Canadian limestone in the southern Appalachian Valley—Character and extent.—Thin to moderately thick-bedded, usually fine grained and in part magnesian limestone of Canadian age is found rather generally in the eastern or Athens trough south of Lexington, Virginia. In southwestern Virginia and in east Tennessee as far south at least as Greenville,

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[100] J. M. Safford: Geology of Tennessee, 1869, p. 147.

this limestone rests on the upper Cambrian Nolichucky shale and hitherto has always been described as a sparingly cherty representative of the Knox dolomite. It is a great valley-maker in this region and very thick. I have measured it at only one place, namely Jonesboro, Tennessee, where the formation, though incomplete above, reaches a thickness of about 1,850 feet. The total thickness in this vicinity is probably 400 feet more, or in all about 2,250 feet. As a rule the early Stones River Mosheim limestone succeeds it.

Gastropods allied to *Maclurea oceanea* and *M. affinis*, and to *Seelya*—types so far wholly unknown in the typical Knox or, indeed, in any Ozarkian formation—occur at intervals in the Jonesboro section to within 400 feet of the top of the underlying Nolichucky. The upper 400 feet of the limestone very commonly contains *Ceratopea keithi* and less frequently other gastropods and cephalopods. Mr. Arthur Keith found this same fauna east of Knoxville in beds referred by him to the upper Knox. As a rule, the fossils are silicified and weather out free from the limestone matrix.

As developed in the valley beginning in the north at Wytheville, Virginia, and extending thence southward to Greeneville, Tennessee, these Canadian limestones are readily distinguished from the dolomitic main Copper Ridge division of the typical Knox by the relatively small amount of chert in them. Cherty bands occur at various horizons in the series, but they form a conspicuous feature of the weathered surface only in the upper 200 or 300 feet and again some 250 to 500 feet above the base. These cherts, however, are quite different from the massive, hard white chert of the Copper Ridge. As a rule, the Canadian chert is often porous; other layers are dense and brittle, platy, mottled, often black, occasionally scoriaceous, and most of it breaks easily under the hammer. Another characteristic is that it is nearly always associated with porous sandstone.

As this formation is a stratigraphic and lithologic unit, and distinct from all others now recognized by name in the Appalachian Valley, the term Jonesboro limestone is here proposed for it.

Canadian deposits were observed locally in the counties of McMinn, Bradley, and Polk in southeastern Tennessee, and near Ringgold, Georgia. These, however, are thin—at a maximum perhaps less than 250 feet—and underlain by Copper Ridge chert. They are fossiliferous, but I have not observed the characteristic species of the Ceratopea fauna in the collections made. On this account it is believed they represent some other age of the period.

Following the general strike of the rocks, the Ceratopea zone is met with again in the west foot of Frog Mountain on the Georgia-Alabama line near Piedmont in the latter State. Here it underlies the Frog Mountain sandstone supposed to be of Oriskany age. How far this outcrop continues southwestwardly is unknown, but in the Cahaba Valley the zone is persistent. At Pelham there must be at least 500 feet of these Canadian limestones. Above them is a well developed middle Stones River section, beneath them the Chepultepec formation. These three formations continue southward in this deep structural trough to the vicinity of Montevallo, near which point Mr. Charles Butts estimates the thickness of the Canadian part of the section at over 1,000 feet. This Alabama representative of the Jonesboro differs sufficiently to make another name desirable. It is therefore suggested that the term Pelham, which as used by the Alabama Survey comprises chiefly Canadian limestones, be restricted to it.

Some may question the propriety of referring the whole of the limestone series beneath the early Stones River Mosheim limestone and down to the top of the Nolichucky shale, in the vicinity of Jonesboro, Tennessee, to the Canadian. In other words, it may be contended that the evidence is insufficient on which these 2,250 feet of limestone are assigned to a position in the time scale above the top of the typical Knox in Tennessee (see page 548), and above the even younger Chepultepec formation in Alabama. In answer to this probable objection I would say that we know (1) that the Ceratopea fauna is confined in Missouri and Arkansas to beds resting unconformably on the Jefferson City dolomite, (2) that the Roubidoux-Jefferson City lies unconformably on the Gasconade, (3) that the Gasconade contains the Chepultepec fauna, (4) that in central Alabama the Chepultepec overlies the typical Knox and underlies the Jonesboro limestone, (5) that the Ceratopea fauna occurs nearly 2,000 feet above the base of the Canadian section in Pennsylvania, (6) that these 2,000 feet of limestone succeed unconformably a cherty formation carrying the Chepultepec fauna, and, finally, (7) that the interval between the Nolichucky shale and the Ceratopea zone in the Jonesboro section is probably less and certainly not greater than the pre-Ceratopea part of the Canadian section in Pennsylvania.

On page 553 I stated that the time relations of the Jefferson City dolomite to the lower part of the Canadian system in Pennsylvania is as yet a matter of opinion. This admission was made because the two zones have not been found superposed in the same section. Still, the case is proved so far as faunal evidence and correspondence in thickness of

deposits can do it. Further, in view of the facts mentioned in the preceding paragraph, especially in the absence of any evidence to the contrary, it seems reasonably established that the Canadian extends to the base of the Jonesboro limestone at Jonesboro, Tennessee.

Regarding the age of the top of the Jonesboro limestone, the position of the Ceratopea zone in other, presumably more complete, sections gives the only competent clue. At Chambersburg, Pennsylvania, the Ceratopea fauna is found 1,100 feet beneath the top of the Beekmantown limestone, which there has a total thickness of about 2,300 feet. Though the Ceratopea has not been observed at Bellefonte, the only part of this great section that at all suggests its zone is the Axeman limestone, which here lies 2,145 feet beneath the top of the Canadian. In Oklahoma the Ceratopea zone was not exactly located in the measured section, but, according to the best evidence now available, it lies not less than 3,000 feet beneath the top of the Arbuckle limestone. According to these data, it appears that the Jonesboro limestone represents only the lower half of the Canadian system as now constituted.

Canadian limestone in Tuckaleechee and Wear coves, Tennessee.—In the Knoxville folio, No. 16, U. S. Geological Survey Atlas, magnesian and pure limestones are mapped in Tuckaleechee and Wear coves, some 20 to 25 miles southeast of Knoxville, as Knox dolomite. These limestones have yielded a few fossils of types unquestionably younger than any so far found in the typical Knox. They are overlain by slates and conglomerates of the "Ocoee series," which presumably have been thrust northwestwardly over them. The limestone forms the floor of the coves and is relatively flat-lying, so that the full thickness is not shown. Still, the irregularities of surface erosion and the slight dip of the rocks cause exposures of several hundred feet in Tuckaleechee Cove.

An incomplete list of the fossils includes the following: *Didymograptus* cf. *bifidus*, *Dalmanella* cf. *electra*, *Protowarthia* cf. *rossi*, *Helicotoma ?* sp. *Hormotoma* cf. *artemesia*. undeterminable fragments of trilobites, and plates of cystidea. Judging from this faunule, the beds are certainly post-Ozarkian. The alliances of the several species strongly suggest middle Canadian zones.

The shale facies of the Canadian—The Levis shale type of sediments.—The Levis shale type of sediments of this period seems to have been deposited in narrow synclinal troughs or channels on the inner border of Paleozoic land masses which then included what are now marginal areas of the North American continent. Judging from the present distribution of the peculiar graptolite faunas which are so characteristic of the Canadian shale formations, one of these channels entered the con-

tinent from the north Atlantic between Newfoundland and Labrador. From here it extended southwestward up the Saint Lawrence trough to northern Vermont, from where it passed in a more southerly direction through this State into eastern New York, presumably joining the Atlantic again in New Jersey. Through most of this extent the deposits in this channel are buried beneath other sediments—slates, limestones, and quartzites, perhaps chiefly of Cambrian age—which have been thrust northwestwardly over them. Here and there the Levis shale is at the surface, but whether this is because the belt was not entirely buried in such places, or whether erosion of the overthrust sheet has again uncovered it, remains to be shown. Besides, we do not yet know exactly how to discriminate the four or five kinds of shale and slate in the Taconic-Saint Lawrence slate belt, unless we are so fortunate as to find characteristic fossils. But no determined and well equipped effort has yet been made to ascertain the lithologic peculiarities of the several beds. Although I have spent but little time in the slate belt, it was sufficient to convince me that serviceable differences in character, association, and sequence of rock types can be worked out. The "slate belt" contains lower Cambrian shales and two Canadian shales, one of them the Levis shale, the other a crumpled and more or less metamorphosed shale that has been pushed westward over various formations, and which seems to constitute the greater part of the "Taconic slates." Besides these the western part at least contains Ordovician shales—the Normanskill and perhaps other distinguishable beds. These four shale zones, I believe, can be discriminated and mapped separately without extraordinary difficulty.

The most southerly outcrop of Levis shale so far discovered is the one on Deepkill, in Rensselaer County, New York, which has been fully described by Ruedemann. He found here an excellent representation of the graptolite faunas long ago collected by the Canadian geologists in the vicinity of Quebec and somewhat later in Newfoundland. That the beds exposed at these three points were laid down in a long channel that communicated at each end with the Atlantic, and may, therefore, have been a current-swept thoroughfare, is inferred from the universally accepted belief concerning the pelagic existence of the graptolites. Being unquestionably floating organisms, therefore dependent on currents for their dispersal, it seems an utter impossibility for them to have floated a thousand miles up a narrow bay, which, so far as I can see, is the only alternative explanation of these longitudinally distributed beds. (See page 371; also paper by Ruedemann in the June issue of this volume.)

Another of these intramarginal channels is indicated by the occurrence of Levis graptolites in the Ouachita trough in central Arkansas and eastern Oklahoma. This channel opened into the Mississippi embayment on the east, and probably extended southwestwardly from Oklahoma through Texas. Its course in the latter State is, of course, unknown, being covered by the late Mesozoic and Tertiary formations which overlap the close-folded and subsequently peneplaned basement of older rocks.

Similar channels are indicated by graptolite shales in western Nevada, but there is some doubt as to the exact age of these. The graptolite fauna at Summit, Nevada, for instance, contains *Phyllograptus*, but with it are many *Diplograptidæ* whose alliances are with Ordovician faunas rather than Canadian. Compared with graptolite zones elsewhere, this Nevada fauna correlates best with the *Diplograptus dentatus* zone of Ruedemann's Deepkill section. Both may be late Canadian, but on account of the preponderance of the Axonophora I am not ready to say positively that they are older than basal Ordovician. However, the Ashhill quarry zone in New York, likewise the upper Tetragraptus zone in Arkansas, shows conclusively that the Axonophora had been developed before the close of the Canadian.

The Ouachita shale in Arkansas.—The Levis shale and fauna, as developed at Quebec and in the Deepkill and Schaghticoke outcrops in New York, is now so well known that it is unnecessary to repeat the information here. A few remarks concerning the equivalent Ouachita shale in central Arkansas, however, seems desirable. The section of which it forms a part has been well described by Purdue.[101] At the base of the section in the Ouachita Mountains is a dark, occasionally graphitic shale, of undetermined thickness (200 feet or more), for which Purdue has suggested the name Collier shale. This is succeeded by the massive Crystal Mountain sandstone, with a maximum thickness of possibly 800 feet. Although fossils have not been found in these two basal formations, I am yet strongly inclined to refer them to the lower Cambrian. Next above is a heavy bed of shale, about 1,000 feet in thickness, to which the name Ouachita shale has been given by Purdue. At its base there is a considerable thickness of sandstone interbedded with black and gray shale, which I am inclined to regard as initial deposits of the Ouachita shale rather than as the upper part of the Crystal Mountain sandstone. The latter interpretation has been adopted by Purdue.

The Ouachita shale consists for the most part of dark clay shale, occasionally alternating with green bands. Thin layers of limestone occur

[601] A. H. Purdue: The slates of Arkansas: Geol. Survey of Arkansas, 1909, pp. 29-52.

rather commonly in the lower half. The next formation is a sandstone, but recently discovered—in a letter from Professor Purdue the name Blakely sandstone is proposed for it—that is absent to the west of Womble, but is locally developed to a thickness of about 500 feet east of that town. The discovery of this intercalated sandstone tends to confirm the high value of the stratigraphic hiatus between the Ouachita and Stringtown shales which hitherto was inferred chiefly on paleontological evidence.

The Stringtown shale consists mainly of soft black shale, but varies greatly in thickness from place to place. It attains its maximum development of 800 or 900 feet where the Blakely sandstone underlies it, but at other places it may not exceed 100 or 200 feet. A limestone, sometimes conglomeratic and 25 to 75 feet in thickness, often occurs at the base of the formation in the latter localities, its place in the formation, according to the section at Crystal Springs, being about 200 feet beneath the top. Beneath this limestone only shale has been observed. Another calcareous zone is locally found at the top, but this even does not seem to be the last deposit of the formation, a still higher graptolite shale being indicated at several localities beneath the overlying Big Fork chert. Fine collections of Normanskill graptolites have been procured from the Stringtown formation. They occur in three zones, clearly distinguishable by characteristic species. The most prolific is the *Nemagraptus gracilis* zone, which lies between the two limestones. Out of 33 species found in one exposure of this zone, 23 species have been listed from the same zone in the Normanskill shale of New York by Ruedemann, and 15 from the Glenkiln shale in England by Lapworth, Elles, and Wood.

The Stringtown is succeeded by the cherty Big Fork limestone, about 700 feet thick, this by the Polk Creek shale, 0 ? to 400 feet, and next by the Blaylock sandstone, 0 to 1,000 feet or more. All of these contain graptolite faunas, comparable with British associations rather than any described from America.

Two graptolite zones have been found in the Ouachita shale. The first occurs in the lower half of the formation near Womble, Arkansas. The species recognized are as follows: *Didymograptus nitidus* Hall, *D. extensus* Hall, *D. similis* Hall, *D. filiformis* Tullberg, *Tetragraptus amii* Lapworth, *T. approximatus* Nich., *T. clarkei* Rued., *T. fruticosus* Hall, *T.* cf. *pendens* E. and W., *T. quadribrachiatus* Hall, *T. serra* Brong., and *T. similis* Hall. Of these 12 species, 8 occur in the Tetragraptus zone and 4 in the Didymograptus bifidus zone in New York and Quebec, while 10 are listed by British authorities from the "Lower Arenig" and "Middle Skiddaw" slates in Great Britain.

The second well marked graptolite zone of the Ouachita shale occurs at some as yet not exactly determined horizon in the upper half of the formation. The best collection was made at a locality about 12 miles west of Little Rock. It includes the following species:

1. *Didymograptus euodus* Lapworth.
2. *D. caduceus* (Salter) Rued.
3. *D. caduceus nanna* Rued.
4. *D.* sp. nov. (near *D. forcipiformis*, but coarser).
5. *Tetragraptus quadribrachiatus* Hall.
6. *T. amii* ? E. and W.
7. *T. pendens* E. and W.
8. *T. clarkei* var nov. (larger).
9. *T. similis* var. nov.
10. *Phyllograptus typus* var. nov.
11. *Diplograptus* sp. undet. (cf. *D. calcaratus priscus* E. and W.).
12. *Mesograptus* sp. undet.
13. *Cryptograptus antennarius* Hall.
14. *C. tricornis* ? Carr.
15. *Glossograptus hystrix* Rued.
16. *Retiograptus tentaculatus* ? Hall.
17. *Caryocaris wrighti* Salter.

Of these numbers 5 to 9 inclusive are found also in the lower zone, but in each case the later occurrence is a distinguishable mutation. The same species, also numbers 2 and 10, occur in the *Didymograptus bifidus* zone in New York and Canada, while numbers 2, 5, 6, 7, and 9 are found in the Skiddaw slates of Great Britain. Numbers 3, 4, 5, 13, 15, and 16—that is, most of the Axonophora—are found in and for the most part confined to the *Diplograptus dentatus* zone in Ruedemann's Deepkill section. However, on account of the strong development of *Tetragraptus* and the presence of *Didymograptus caduceus* in this Arkansas fauna I regard it as older than the *Diplograptus dentatus* zone and as approximately equivalent to the Ashhill Quarry zone, which Ruedemann places as a "transitional subzone" between the *Didymograptus bifidus* and the *Diplograptus dentatus* zones.

Age of the Dictyonema flabelliforme and Olenus zones.—A point on which I differ more or less from American authors concerns the age of the *Dictyonema flabelliforme* zone, which is usually given as upper Cambrian, but which I regard as not only post-Cambrian, but also post-Ozarkian—in other words, as Canadian. A welcome tendency recently manifested among the best Swedish stratigraphers is to place this zone above the Cambrian. My proposed arrangement of the *D. flabelliforme* zone, therefore, accords essentially with theirs. The differences in our respective views arise from the fact that I intercalate an intermediate system—the Ozarkian—between the top of their Cambrian and the base of their Ordovician (or Silurian), which they begin with the Dictyonema zone. That I promote the Canadian to the rank of a system and begin the Ordovician with the Saint Peter in the Mississippi Valley and with the first sediments of the Chazyan invasion in the Appalachian province

is only a matter of refinement in classification that the Swedish geologists with their imperfect section could not anticipate.

That the Dictyonema zone is post-Ozarkian and not greatly older than the Tetragraptus fauna is strongly suggested by the close alliance of *Bryograptus, Clonograptus,* and *Staurograptus,* species of which genera often accompany *Dictyonema flabelliforme,* to *Goniograptus* and the *Dichograptidæ* generally that are found in the Tetragraptus zone. Indeed, *Bryograptus* and *Clonograptus* are common to the two zones. *Dictyonema flabelliforme,* besides, is too much like subsequent species of the genus to suggest a much greater age than Canadian. Considering the extraordinary rapidity of the evolution of the graptolites, especially the *Dichograptidæ,* during the middle and earlier stages of the Canadian, it seems unreasonable to assume that a long geological time was required to overcome the really small differences between the older species of *Clonograptus* and *Bryograptus* on the one side and the later species of these and closely allied genera in the Tetragraptus zone on the other. That both zones belong to the same broad stratigraphic division is strongly indicated by the field relations of the beds holding the respective faunas. No break, either stratigraphic or lithologic, has so far been discovered between them, and, in my opinion, there is none of great consequence—certainly none of the importance it would have to be if the *D. flabelliforme* zone were upper Cambrian. Both are found in precisely the same kind of sediments, so that without the fossils it has seemed impossible to discriminate between them. While thin conglomerates are common they are clearly intraformational, being found interbedded with successive beds containing the same fauna. Under the circumstances my reference of the Dictyonema zone, and with it most—perhaps all—of Matthew's Bretonian, to the Canadian, requires no apology.

The true relations of the Olenus fauna with respect to the Ozarkian and the Canadian are not easily determined. The problem is exceedingly complicated, many factors entering that can not be touched here. If the Bretonian—the lower half of which contains the Olenus fauna, in part associated with *Dictyonema flabelliforme*, while its upper member contains the Tetragraptus fauna—is, as thought by Matthew, a practically continuous deposit, I see no good reason why the whole of the group or formation should not be referred to the Canadian. The faunas living on the exterior platform of the continent, being adjacent to the permanent oceanic deeps, may reasonably be expected to exhibit greater persistence than the epicontinental faunas—a probability that may account for the Cambrian and Ozarkian aspect of the Olenus fauna.

In New Brunswick and Cape Breton the early Paleozoic section is essentially the same as in Sweden and Norway and similarly incomplete. In each of these areas it seems to me that Cambrian sedimentation ceased with the middle Cambrian, and the Olenus fauna, which succeeds the middle Cambrian, in Scandinavia as in the maritime provinces of Canada, is thought to be early Canadian in age. The hiatus between the middle Cambrian on the one hand and the Bretonian and "Olenidian" on the other, therefore, would correspond to the upper Cambrian of the Mississippi and southern Appalachian valleys plus the whole of the Ozarkian.

Briefly noted, the Canadian of America, as here interpreted, seems to correspond to the following European formations: In the Baltic section, to the beds between the base of the Olenus slate and the top of the Ceratopyge beds; in England, the corresponding interval includes the Tremadoc and Arenig, beginning with the Olenus and *Dictyonema flabelliforme* zones and extending upward to the top of the *Didymograptus murchisoni* zone of Lapworth. In Bohemia the evidence in hand is not satisfactory. Here probably only the Brda zone (D 1^a) is positively referable to the Canadian. The Komorau zone (D 1^b) is classified by Katzer as Cambrian, transitional to the Ordovician. The fauna as listed contains some graptolites strongly indicative of Canadian age. Other fossils, however, like *Echinosphærites ferrigena* and species of *Conularia* suggest only post-Canadian. Possibly the lower part is Canadian and the upper Ordovician, or it may be another case of the survival of vigorous species into a succeeding age.

NOTE.—It is understood that it is the author's intention to publish additional matter on this subject.—EDITOR.

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FIGURE 1.—BIRD'S-EYE VIEW OF MOUNT TOBY

FIGURE 2.—HANGING VALLEY ABOVE "a" IN FIGURE 1

The brook (+) in the center of the figure drains a broad, flat area, of which the high ground in the center of the picture forms the back wall. The brook falls over the vertical wall 80 feet lower than the sand plain in the foreground.

RELIEF MAP OF MOUNT TOBY AND VIEW OF THE HANGING VALLEY INDICATED THEREON

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CIRQUES AND ROCK-CUT TERRACES OF MOUNT TOBY[1]

BY B. K. EMERSON

(*Offered to the Society for Publication October 24, 1911*)

CONTENTS

Introduction

Mount Toby, in Sunderland, 8 miles north of Amherst, is the highest elevation in the Triassic area in Massachusetts.

It presents two unique topographic features—one a group of radiating cirques which show many of the characteristics of glacial cirques, but which may seem to be on too small a scale to have this origin, and the other a series of rock-cut terraces with vertical walls 10 to 150 feet high, which are confined to the west side of the mountain.

The Cirques

I owe the bird's-eye view of the mountain (plate 30, figure 1), which shows the condition of things with great clearness, to the skill of my daughter, Mrs. Charlotte E. Hitchcock. There is some necessary exaggeration and some intentional disregard of the ordinary laws of shading in order to bring out all the steep-walled radiating depressions.

The cirques do not appear so clearly as they should on the topographic map of the mountain, because the contour lines are there drawn so as not to touch where walls 60 feet or more in height are quite vertical. These contours are generally very incorrect, and especially so in two important places. The main ridge of Mount Toby should be continued south beside the railroad a mile farther than is shown on the map, and the deep depressions in the southwest side of the mountain are omitted, as well as the corries at the north end.

[1] Manuscript received by the Secretary of the Society May 31, 1911.

Eight cirques have been cut deep into the heart of the mountain, so that what remains is rather a set of steep-walled radiating ridges—a skeleton of the former mass.

It is tentatively assumed that these cirques are of glacial origin, because (1) they radiate in all directions from the center of the mountain, and are so approximated as to leave apparently no place for the gathering or outflow of running water by which they could have been carved; (2) they have steep walls and a flat bottom, and head in a steep rounded wall like the bergschrund of a glacier, and end in hanging valleys overlooking the main basin of the Connecticut, and (3) in one case glacial scratches remain in the side of a cirque running at right angles to the flow of the main glacier, as described below.

It is assumed also that they are of early glacial origin, because they have no lateral or terminal moraines of local origin. Their bottoms are, however, deeply covered by the general foreign till and their mouths are sometimes clogged by the shore beds of the Connecticut Valley lake, which followed the disappearance of the ice. They can not have been produced by faulting, because the trap band crosses several of the more important valleys continuously, and, as it has a very low dip to the east, any faulting which could have caused these valleys would have made great offsets in this trap sheet. Moreover, the heavy trap bed crosses the bottom of several of the depressions and is planed down to the common level, which is more indicative of ice than of water action.

Starting at the southwest corner, there is an interesting double cirque (*a*) (plate 30, figure 1) one-third of a mile wide, which appears to have been occupied by a cascading glacier.

The upper basin has a swampy bottom without inlets, and the steep semicircular boundary wall can hardly have been worn by water. The outflowing brook which jumps over the brink at the point indicated by the cross in plate 30, figure 2, and into the deep lower cirque has not worn back at all in the rock.

Next northwest there follows a very small corrie (*b*), with swampy bottom and a fine hanging valley in the vertical wall (plate 31, figure 1).

From a later examination it is believed that this small depression is an early abandoned lobe of "*c*," as shown in figure 1, plate 30.

A wood road extends east into the mountain along the north side of this corrie, and 88 rods up this road the pebbles of the conglomerate are clearly polished and striated, the striæ running south 15 to 20 west, and 18 rods farther on, where the road overhangs the brook, there are perfect horizontal striæ along the vertical wall, which there runs south 35 west. These are directions following the axis of the valley at these points and

FIGURE 1.—HANGING VALLEY AT "b" IN PLATE 30, FIGURE 1.

The vertical wall at the head of the corrie can be distinctly seen, and on the right are three vertical scarps mostly concealed by the heavy timber. The southwestern striæ are found beneath the high trees which project against the sky.

FIGURE 2.—VERTICAL SCARP FORMING PART OF WALL OVER WHICH FALLS THE BROOK SHOWN IN FIGURE 2, PLATE 30

It is continuous at least 80 feet below the level of the sand plain in front

HANGING VALLEY AND VERTICAL SCARP: MOUNT TOBY

exactly at right angles to the trend of the main glacier. They must thus have been formed by the small glacier which filled the valley, and they are on the lee side of the ridge, exactly where they could not have been made by the main ice and where they are sheltered from the subsequent action of the same. An arrow at "*b*," on figure 1, plate 30, indicates the average direction of the ice.

The next cirque, "*c*," is entered by the "south sugar road" at a point a mile due east of Sunderland street, and a south branch of this road can be followed for half a mile farther into the heart of the corrie, which is surrounded by steep walls 60 to 80 feet high.

The main sugar road mentioned above conducts one also into the largest of these amphitheaters, "*d*," which is a mile and a half long and nearly a mile wide in its upper two-thirds, but contracts considerably toward the mouth, where it is confluent with the one last described, and continues beneath the sands. It has very steep and high walls except around its broad head, where the slope is more gradual. The four great steps of the narrow tongue between the lobes of this compound valley are very striking.

The next two corries, "*e*" and "*f*," complete the row of those facing westward. They are not so clearly marked as the others, and show quite clearly that they have not been preserved so nearly intact, but have been partly planed away by the later ice-sheet. The southern of the two, which faces due west, and is entered by the "north sugar road," is perfectly preserved in its south and east walls. The latter is a steep bergschrund 500 feet high. The parting between this and the northern one is clear, but not steep, and only the innermost portion of the northern one is preserved. It differs from the others also in that the bottom is crossed by the many vertical terrace scarps almost as high and well marked as on the ridges. It is just here at the northwest shoulder of the mountain, where the impact of the main ice from the northwest would be strongest, that the wearing away of the former corries is most apparent.

On the northeast of the mountain is a great depression which is its most prominent feature, as seen from the north. It is at first a single cirque, "*g*," bounded at its head by a great bergschrund a mile long, which has eaten back westerly, and between it and the head of the cirque on the west is left a narrow steep-walled ridge forming the crest of the mountain, and only just wide enough for a carriage road. Lower down, this northwest cirque divides into two, "*h*" and "*j*," which end as high hanging valleys.

The southern half of the east wall of the mountain is notched high

up by four incipient hanging valleys, "*k-n*," which could not be represented on the figure.

The objections to this glacial hypothesis are certainly serious. Mount Toby is a mount rather than a mountain. I have seen very small glaciers in Yakutat Bay, Alaska, and farther north, but I doubt if any quite as small as these have been found.

Again the Worcester County plateau, 1,200 feet high, comes up to within 3 miles of the mountain on the east. Mount Toby is 1,265 feet high, and 12 miles to the west begins the Berkshire County plateau at 1,400 feet. It may be urged that the ice gathering over these high areas would become confluent with that of Mount Toby before much independent work had been done to the mountain itself. This has not quite so much force as the former objection, since as the ice moved from the northwest the great vertical-walled westward facing trap ridge of Deerfield Mountain (which stands west of Mount Toby, extends north through Greenfield, and bends round to the east in Gill) certainly did fend off the ice from Mount Toby in a considerable degree, as the direction of the ice scratches show, and may have protected it until the main Berkshire ice had gained a considerable thickness. Both here and at the Holyoke range the ice impinged very obliquely against the trap ridge and went south at its foot a long way before it rode obliquely over it, as a carriage wheel escapes from a trolley track. From this cause the soft sandstones stand several hundred feet higher east of the Holyoke range than west of it, and preserve the preglacial stream beds, and this protection is the main cause of the height of Mount Toby.

It is certainly very difficult to realize on the ground how these closely approximated corries can have been formed by ordinary water erosion. If they were thus formed the time required must have been very great, since the supply of water must have been very small. Faulting, however, may have had more influence than is admitted in the above description, since faults are hard to locate in these monotonous conglomerates where the trap is wanting.

The Terraces

One needs to consider also the moderating and modifying influence of this trap barrier on the impact of the continental ice against Mount Toby in studying the second peculiarity of the mountain—that is, its rock-cut terraces.

The whole western wall of the mountain on all the ridges and intervening slopes between the cirques has been cut into a series of great rocky

westward-facing terraces marked by steep or even vertical walls from 10 to 150 feet in height.

Because of the low dip of the beds to the east the gain in elevation in climbing a terrace scarp is lost in going east with the dip across the terrace flat, and this makes possible the many miles of vertical scarps which flank the mountain. The rock is a coarse conglomerate with some intervening finer and softer beds, and much jointed. The ice has taken advantage of these master and minor joints in its work, and has carried this forward with the regularity of a great quarry. A nearly horizontal and softer bed has furnished the floor and a vertical joint the face, and the courses have been carried east on a grand scale and with wonderful symmetry.

Whether the deep corries were made by ice or by water, it is assumed that the terraces were formed later than the corries by the plucking of the continental ice after it had reached such thickness that it had established its south-southeastward motion. The lack of these terraces in the bottom of the corries is explained by their depth and by the assumption that the ice and till filling the corries was overridden by the main ice, and so the plucking action was not marked there. The fact that the terraces do run across the bottom of the northwest corries is explained by their position where they received the strongest impact of the ice, and so their borders were worn down and their bottoms scoured free from till and somewhat eroded with the formation of low terraces.

The fact that the terraces are found only on the west side is strong indication that they were not caused by normal weathering and recession of escarpments, for the beds are almost horizontal and emerge on the east side of the mountain, and, if ordinary weathering had caused the recession of the escarpments on the west side, similar and more perfect escarpments should appear on the east side (since the dip would favor them there), instead of an almost vertical wall. A great fault, however, runs at the east foot of the mountain, and it may be urged that the downthrow of that fault removed an eastern portion of the mountain around which the terrace scarps were formerly continued.

But the clearly observed throw of that fault is only 100 feet, and could not explain the sheer face of the mountain 700 feet high. Moreover, these faults occurred near the end of the Triassic, and thus at the beginning rather than at the end of the long erosion period during which the scarps were cut back according to the hypothesis of erosion by weathering.

A considerable fault runs at the foot of the high bluffs east of the points indicated by letters "*f*," "*e*," and "*j*" on figure 1, plate 30, and may be in part responsible for the exceptional height of these bluffs.

These scarps can not have been formed by water or ice moving parallel to the direction of the valley, since they are lacking on the opposite western side of the valley as well as on both sides of the next valley to the east. They are also marked by reentrant angles and projecting bastions, as if the great blocks had been quarried out, and there is no talus of such blocks at the foot of the bluffs. Moreover, the bottom of each scarp is not carried along at a constant level, as if controlled by a shore line, but rises and sinks, or branches, often plainly controlled by the eastward dip of the rock combined with the direction of the mountain side.

We must, I think, come back to the opinion that the sheltered position of the mountain behind the Deerfield range may have caused the late advent and peculiar action of the main ice on the mountain, and have been largely responsible for its peculiar position and shape, and especially that it so directed the attack of the ice as to cause the formation of the terraces. Whether it held back the ice so that small glaciers cut out the cirques, as I have thought, or whether they were made by slow headward wear of surface waters, combined with faulting, may be left undetermined.

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MID-CONTINENTAL EOLATION[1]

BY CHARLES R. KEYES

(Read by title before the Society December 27, 1910)

CONTENTS

INTRODUCTORY

In the recent considerations of subaërial formations so many novelties enter that in many an old and well known field a new interest is aroused.

[1] Manuscript received by the Secretary of the Society August 11, 1911.

Prominent among such tracts is the country lying between the Rocky Mountains and the Mississippi River. Both for the origin of the vast plains surface and of the so-called fresh-water Tertiaries underlying it a more satisfactory explanation than any yet offered is now demanded.

The Great Plains appear to display the effects of a general leveling process to which but scanty attention has been given. On a grand scale they seem to introduce to us a mode of terranal genesis hitherto almost unrecognized. Continental deposits thus begin to assume in this country an importance which has been never before accorded them.

The vast areal extent of the Great Plains terranes, their remarkable uniformity in lithologic character, their unusual evenness or vagueness of stratification, and their fineness and homogeneity of texture long marked them as lake-formed deposits. Only recently has this generally accepted interpretation of their genesis been seriously called into question. As Davis[2] well observes, there has been no critical discussion of the proofs upon which the bare assertion of their lacustrine origin rests.

When the lacustrine hypothesis is closely examined there appear many incongruities in its unqualified application to the entire Great Plains region. In order to overcome some of the most glaring obstacles aggrading aid from present rivers is invoked. To this also there is serious objection. There is, however, a third geologic agency which is now known to be involved, of which little reference has yet been made. This is the potent activity of the wind, both in degradation and in aggradation, in and bordering arid and semi-arid regions.[3] To certain aspects of the last mentioned agency attention is here mainly directed.

Since, according to Murray, one-fifth of the entire land surface of the globe is occupied by desert,[4] and another one-fifth is susceptible to a greater or less accumulation of continental deposits of one sort or another, subaërial formations come in for larger interest than it has been customary to accord them. Of the United States fully one-third may be regarded as arid, and a like large part may be considered as more or less appreciably affected by subaërial deposition. In the past deposits now regarded as continental in character have been usually explained on the theory of water-action alone. Even in the Great Plains region processes of the sea, the lake, and the river have been all drawn upon to account for the phenomena presented, often where the wind appears to be almost the sole erosive agency involved.

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[2] Bull. Geol. Soc. America, vol. 11, 1900, p. 598.

[3] McGee's appropriate term eolation in its original general sense is adopted; it covers all phases of wind-action, the destructive phase being known as deflation and the constructive phase as aëroposition.

[4] Science, vol. xvi, 1890, p. 106.

Concerning both the stratigraphy and the relief of the region, there are few details to add to those contained in the already quite voluminous literature on the subject. The published observations of geologists who have traversed the area are acceptable without dispute. The tectonic descriptions given by them abundantly corroborate one another. Only the interpretation of some of the recorded facts are open to question. The foundation of the interpretation here offered lies mainly in the records of personal observations of a rather comprehensive character. The generalizations derived from the observed facts are soon stated.

Dominant Characteristics of the Great Plains

The origin of the most striking and characteristic features of the Great Plains has never received adequate explanation. Although these several characters have repeatedly been the subject of extended notice, there has been little attempt to refer them directly to the geologic processes to which they owe their origin. Five features in particular attract first attention: (1) The great extent and uniformity of the substructural terranes; (2) the remarkable evenness of the surface relief; (3) the peculiar loamy or marly nature of the deposits; (4) the general vagueness of stratification, and (5) the manifest recency of deposition.

It is indeed a suggestive fact concerning their genesis that the Great Plains deposits have been traced so continuously southward from the Dakotas to New Mexico, where, at the southern end of the Rocky Mountains, under conditions of arid climate, they are correlated with the Galisteo sands and the Santa Fe marls of Hayden[5] and desert adobe—typical soils and formations of the desert. Still farther southward indistinguishable deposits continue far into Mexico. From this it may be inferred that the "lake beds" of the Great Plains are of wide distribution; that they apparently have in great part a similar origin; that they merge imperceptibly into other formations, and that different parts are of quite different geologic age.

Long before the Great Plains region had come under the critical surveillance of the physiographer its most distinguishing feature was accurately described when it was characterized as an illimitable expanse of flat, treeless country almost untrenched by streams. This most striking feature is, then, the remarkably even plain of such vast extent. Only in the northern part, where traversed by the Missouri River, and in the immediate vicinity of that stream, are the Great Plains notably trenched. There, on account of certain peculiarities of texture which the substruct-

[5] Third Ann. Rept., U. S. Geological Survey of the Territories, 1873, p. 167.

ure presents, the so-called *mauvaises terres* result. The topographic modifications of the eastern border, for reason of the nearness to moist climate conditions and the prevalence of normal streams, are described in another connection.

A remarkable characteristic of the Great Plains formations, and one which has always been a fertile theme of discussion, is its peculiar loamy texture. In this respect they closely resemble the loess. Their homogeneity of texture over wide areas and through great thicknesses is a feature which has long been puzzling.

The stratigraphy of the Great Plains formations is singularly obscure. In the relatively few tracts and small areas in which outcrops are well displayed the finer materials are disposed in layers so thin and even that they might be easily mistaken for lamination produced by deposition of sediments in quiet waters. On the other hand, certain gravel trains near the Rocky Mountains point at once to fluviatile action.

The title Fresh-water Tertiaries, long applied to the Great Plains deposits, fairly indicates general opinion regarding their genesis and geologic age. Later investigations show conclusively that under this term are included deposits of all ages from early Tertiary to the present. The most noteworthy determination is that of the extreme recency of the major portion of the exposed terranes.

Explanations of Plains Formations

GENERAL STATEMENT

Unlike the case of the majority of geological formations, the substructure of the Great Plains has had ascribed to it every known method of sedimentary origin. Its surface relief has been also variously accounted for. From the time when the deposits were first brought to public notice and the entire region thought to be the upraised bottom of the sea, until the present day, no less than half a dozen hypotheses of origin have been advocated.

In this one formation and in this single topographic feature is reflected in all its phases the trend of sedimentative and physiographic thought in America. For this reason alone the theme merits more than passing note. Critical criteria may be evaluated and compared as is nowhere else possible in this country.

MARINE DEPOSITION

From the first the great interest in the geology of the region under consideration centered in its post-Paleozoic history. The early expedi-

tions of Lewis and Clark in 1804-6, of Nuttall in 1818, of Long in 1819, of Nicolet in 1839, and of Owen in 1849 brought back many Cretaceous and Tertiary fossils, and for the entire region the general conception of an upraised sea-bottom prevailed. Even so late as the year 1890 Cross[6] refers to the Table Mountain basalt, near Golden, as long "submerged in the Denver sea." It is for this reason, doubtless, more than any other, that the more recent discovery of an abundance of non-marine organic remains at once gave rise to the notion that the extensive terranes of fine loams represented deposits of vast fresh-water lakes rather than of old seas.

Without exception, the accounts of the so-called fresh-water Tertiaries of the Great Plains seem to be arguments against the theory of their marine deposition rather than a marshalling of facts in support of the possible lake origin which was claimed for these deposits.

LACUSTRINE ORIGIN

The first suggestion that the mid and late Tertiary deposits lying east of the Rocky Mountains were laid down in vast fresh-water lakes appears to have been made in 1852 by Dr. John Evans,[7] who three years previously had conducted the government geologic explorations on the upper Missouri River. In writing of the profusion of organic remains which he everywhere encountered he observes that "all speak of a vast fresh-water deposit of the early Tertiary period." D. D. Owen, under whose official direction these explorations were undertaken and who edited Evans's notes, does not seem to agree with him, but adopts the old view of marine formation.

Without discussion or setting forth of evidence, and without referring to Evans's published observations, Hayden[8] also proposes formally the lacustrine hypothesis, since which time, and with no attempt at critical examination of the fundamental data, it has been generally accepted. The idea appears to have originated in the circumstance that whereas at the base of the great sequence the beds contain oyster shells and other marine remains, higher up are found some land and fresh-water shells, the bones of many land animals, and remains of plants. In support of a lacustrine origin of the deposits considerable weight is attached to the fact that there is vast extent and great thickness to the marly silts and fine sands composing the formations.

The list of writers supporting the lake hypothesis is a long one. Sin-

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[6] Proc. Colorado Sci. Soc., vol. III, 1890, p. 124.
[7] Geol. Survey of Wisconsin, Iowa, and Minnesota, 1852, p. 197.
[8] First Ann. Rept. U. S. Geological Survey of the Territories, 1867, p. 58.

gularly there is little discussion of the proofs. Among the most important references are those of Newberry,[9] in his descriptions of the "Ancient Lakes of Western America"; of Powell,[10] in various of his reports; of King,[11] in discussing the "Geology of the Fortieth Parallel"; of Newton,[12] in his "Geology of the Black Hills"; of Dutton,[13] in the "Geology of the High Plateaus of Utah"; of Cope,[14] in many of his detached notes, and of Marsh,[15] in picturing the probable environment of the "Dinocerata." In the Correlation Papers summing up general opinion regarding American terranes, both Clark[16] and Dall and Harris[17] accept without question the lake theory. Among the most recent references to the subject Barbour[18] and Darton[19] hold unreservedly to the lacustrine origin of the terranes.

The present plains surface, according to the lacustrine hypothesis, is merely the even lake bottom after the withdrawal of the waters.

STREAM PLANATION

Of late years, since it has become the custom to ascribe all plains effects to the general leveling tendency of river action, most writers on the Great Plains region have, without referring to the earlier lacustrine hypothesis, regarded its dominant relief feature as due directly to this process. Among text-books on geology Gilbert and Brigham,[20] for example, state that "the greater part of the vast area is a worn-down plain; rocks which were formed by the sea or by lakes have been exposed for ages to the action of swinging rivers and have been pared away until the grade is even from the mountains at the west to the central lowlands."

In his recent notes on the Great Plains, Johnson[21] ascribes to them a complex origin. The Tertiary and Quaternary substructure he regards as alluvial when the climate was more widely arid than now. The present surface relief of the central belt, or High Plains area, is called a remnant of the original stream-built surface or an upland of survival. To the eastward, where the country is irregularly undulating, it is regarded as

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[9] Fourth Ann. Rept. U. S. Geological Survey of the Territories, 1871, p. 333.

[10] Colorado River of the West, 1875, p. 150; also Geology of the Uinta Mountains, 1876, p. 163.

[11] Geological Survey of the Fortieth Parallel, vol. i, 1878, p. 457.

[12] Geology of the Black Hills, 1880, p. 188.

[13] Geology of the High Plateaus of Utah, 1880, p. 158.

[14] American Naturalist, vol. xvi, 1882, p. 177.

[15] Monograph U. S. Geological Survey, vol. x, 1886, p. 6.

[16] Bull. 83, U. S. Geological Survey, 1891, p. 111.

[17] Bull. 84, U. S. Geological Survey, 1892, p. 175.

[18] Bull. Geol. Soc. America, vol. 8, 1897, p. 307.

[19] Nineteenth Ann. Rept. U. S. Geological Survey, 1899, pt. iv, p. 719.

[20] Introduction to Physical Geography, 1902, p. 164.

[21] Twenty-second Ann. Rept. U. S. Geological Survey, 1902, pt. iv, p. 637.

recently degraded on account of the heavy precipitation of a humid climate, while the desert portion to the west is a degraded surface because of the light precipitation of an arid climate.

FLUVIATILE AGGRADATION

The necessary conclusion that after issuing from the mountains heavily loaded streams must, on account of the abrupt diminution of gradient, drop a considerable part of their burden doubtless has given rise to the deduction that in the case of the Great Plains deposits they also are entirely of aggradative origin.

So far as I have been able to ascertain, Gilbert[22] appears to be the first to call into question the generally accepted notion that the Great Plains deposits were strictly lacustrine formations. In eastern Colorado he regards the Tertiary deposits as mainly due to stream-work, but aided somewhat by wind-borne dust and sand and some slight augmentations of lake silts. Haworth,[23] from his study of the deposits as displayed in the western and central portions of Kansas, concludes that lake beds are few in number and small in extent, but that the major part of the formations are essentially river deposits.

Farther north, Matthew[24] sets forth considerable evidence to show that the White River Tertiary beds may be of eolian origin. Davis,[25] after a visit to the Great Plains in company with Penck, formulates his reasons for assigning to the deposits in question a strictly fluviatile origin. This particular aspect of the problem is considered in detail elsewhere.

WIND-SCOUR AND ITS EFFECTS

Although specific work of the winds on the Great Plains has never been critically discussed, there has been occasional reference to eolic activities. A dozen or more years ago[26] it was pointed out that the wind should be regarded as a potent factor in the formations of the great loess deposits along the Missouri River in the prairie region of the Great Plains." This view was further emphasized by Bain, Leverett,[27] and others. Winchell[28] graphically describes the powerful effects of a dust storm in the Dakotas. Farther south, in the New Mexico part of the plains region, Tarr[29] men-

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[22] Seventeenth Ann. Rept. U. S. Geological Survey, 1896, pt. ii, p. 575.
[23] Univ. Geol. Surv. Kansas, vol. ii, 1897, p. 281.
[24] American Naturalist, vol. xxxiii, 1899, p. 403.
[25] Proc. American Acad. Arts and Sciences, vol. xxxv, 1900, p. 345.
[26] American Jour. Sci. (4), vol. vi, 1898, p. 299.
[27] Zeitsch. f. Gletscherkunde, iv Bd., 1910, p. 229.
[28] American Geologist, vol. iii, 1889, p. 397.
[29] American Naturalist, vol. xxiv, 1890, p. 457.

tions similar experiences. Udden[30] describes many such storms which occurred during the years 1894-5.

In referring recently to the dominant features of the region lying between the Mississippi River and the Rocky Mountains, I made[31] the observation that general desert-leveling, chiefly through eolation, is doubtless much more extensive than has been commonly supposed; that in the presence of water action, especially since water is the most familiar of the erosive agencies, the effects of wind-work are apt to be largely overlooked, and that eolation is probably an important aggrading process far beyond the limits of an arid region, though its influence rapidly diminishes as the annual amount of rainfall increases. In support of these statements it was noted that while the eastern limits of the American arid region may be taken as the western boundary of Texas and Kansas, eolative activities are appreciable so far east as the Missouri River, and even beyond. "The region lying between the arid belt and the Missouri River was not so very long ago believed to owe its smoothness chiefly to the fact that it was once occupied by Tertiary lakes. Later it was thought that the plains expression was largely the result of fluviatile deposition. It now appears more probable that these plains were fashioned mainly by eolation."[32]

AËROPOSITION EAST OF THE ROCKY MOUNTAINS

Incidentally a number of references are made to eolian deposits on the Great Plains. Cannon,[33] for instance, observes that in eastern Colorado "the heavy deposits of loess that mask the entire plains country attain near Wray, on the Burlington and Missouri River Railway, a thickness of over 225 feet." . . . "On the 'flats' between the streams the loess is covered by extensive superficial deposits of eolian origin." In discussing the question, "Is the White River Tertiary an eolian formation?" Matthew[34] ascribes the sandstones to possible river action, but the clays seem best to accord with eolic activity, "such as is now going on in the production of the loess on the open grassy surface of the sub-arid plains."

That extensive wind-laid terranes are to be included among continental deposits of this country is a still more recent suggestion which I have made concerning the origin of the Great Plains formations.[35] As stated, the important eolic deposits are to be expected on the leeward side of arid

[30] Popular Science Monthly, vol. xlix, 1896, p. 655.
[31] Bull. Geol. Soc. America, vol. 21, 1910, p. 585.
[32] Loc. cit.
[33] Proc. Colorado Sci. Soc., vol. iii, 1890, p. 215.
[34] American Naturalist, vol. xxxiii, 1899, p. 403.
[35] Proc. Iowa Acad. Sci., vol. xix, 1911, p. 200.

tracts, where the exported dusts of the deserts come to rest under conditions of moist climate and abundance of vegetation. Such deposits are now believed to be very much more extensive than there is at the present time any general notion of. Among the examples specifically enumerated are the so-called fresh-water Tertiaries of the Great Plains, certain loamy deposits around the Caspian Sea, extensive siltlike formations in northern China, and some of the coarser deposits bordering the Nile.

Origin of eolic Continental Deposits

RELATIONS OF AREAS OF DENUDATION AND DEPOSITION

Although the activity of the wind as a geologic agent is widely admitted, its potency as an erosive power comparable to that of the river or the sea is not so generally recognized. From the recent literature on eolic formations it is to be inferred that wind-formed deposits are laid down within the limits of the arid regions themselves. Such inference is quite incorrect. The areas of eolic denudation and deposition are as distinct and as widely separated from each other as are the corresponding fields of streams.

Since deserts are mainly areas of rapid degradation, extensive terranal accumulation is not to be expected; they are the tracts of maximum deflation. The dust-ladened air currents flow outward in all directions from the desert, just as the rivers radially leave a chief mountain uplift and pursue their courses toward the sea—their areas of deposition. The loads of the air streams are finally dropped in the semi-arid and moist climate belts far outside of the areas where desert conditions prevail. In every desert area great sand-dunes there are on every hand, low mounds and low ridges of finer materials frequently occur, and the entire surface is mantled by a fine pulverulent loam; but all these are quite ephemeral in character. They are soon swept away or exported beyond the desert boundaries. They are constantly replaced by other accumulations of like nature and magnitude.

It can not be too often emphasized that areas of deflation and of aëroposition are not identical; that they overlap at but few points, and that the one represents destructive erosion, the other constructive gradation.

CLIMATIC PECULIARITIES

Of the climatic conditions peculiar to desert regions only one or two points need be referred to here. The factors highly influential in the production of materials for eolic deposits are deficient rainfall, clear skies, high evaporation, great range of diurnal temperatures, and sparse

vegetation. There is general agreement among recent writers on the subject that the conditions thus imposed are productive of terranal and topographic contrasts much stronger than those displayed in humid lands. Certain it is that in arid areas such features as rock-wasting mainly mechanical in nature, dry and pulverulent soils, plant growth which does not bind the soils, indefinite waterways and few, and winds constant and strong, have no counterpart in moist countries. Erosional conditions with which we are most familiar are absent to an extent which is hard for us to fully realize. They are in pressing need of critical review from vantage points other than those commonly selected.

DEFLATION IN DRY REGIONS

Since the appearance of the recent publications of Walther,[36] Parsarge,[37] Bornhardt,[38] Cross,[39] and others on the various phases of erosion displayed in arid region, wind action as a degradational process is made in every way comparable to general stream planation under the most favorable circumstances. Under the stimulus of aridity, wind-scour becomes, as lately set forth in some detail,[40] an erosive agent more constant than any workings of the rain, more potent than corrasion of streams, and more persistent than the encroachment of the sea.

As is now well known, areas in which the annual rainfall is less than 10 inches, in which typical desert conditions prevail, are little eroded by water, while the degrading effects of wind-scour reach their maximum efficiency. Under these conditions the wind is often the sole eroding agency. It has been lately urged[41] that in the case of arid tracts of southwestern United States general desert-leveling and lowering of the country has been accomplished largely by the wind. The desert ranges are regarded as developed through means of differential eolic effects upon alternating belts of resistant and weak rocks. Between the initial plains level, represented apparently by the tops of existing ranges, and the present general plains surface, represented by the even intermont plains, no less than 5,000 feet of rock material seems to have been removed.

In the transportation and exportation of this rock waste by means of the wind, quantitative data are now available. The air stream carries fine dust debris many times the volume that rivers do. This being the

[36] Das Gesetz der Wüstenbildung im Gegenwart und Vorzeit, Berlin, 1900.
[37] Zeitsch. d. deut. geol. Gesellschaft, lvi Bd., Protokol, 1904, p. 193.
[38] Zur Oberflächengestallung u. Geol. Deutsch-Ostafrikas, Berlin, 1900.
[39] Bull. Geol. Soc. America, vol. 19, 1908, p. 53.
[40] Bull. Geol. Soc. America, vol. 21, 1910, p. 566.
[41] Bull. Geol. Soc. America, vol. 21, 1910, p. 587; also Journal of Geology, vol. xvii, 1909, p. 31.

case, there must be extensive areas to receive the wind-borne dusts, for the latter can not be all transported to the ocean by the through-flowing rivers of the desert nor by the streams of the contiguous semi-arid and moist belts.

The possible formation of desert plains of southwestern United States and the tremendous differential action of deflation upon hard and soft rocks in the Great Basin and the Mexican tableland are by no means exceptional occurrences.[42] To vast deflative action is now ascribed the surface expression of so many of the arid tracts of the globe that there seems to be no longer any question of the verity of the process. In addition to the references given, mention may also be made to the conclusions of Petrie[43] in the Nile delta, La Touche[44] in the Indian peninsula, of Berg[45] in Siberia, of Ivchenko[46] in central Asia, of Hundhausen[47] along the southern coast of France, of Davis[48] in South Africa, of Hume[49] and of Barron[50] in the country between the Nile and the Red Sea, of Hill[51] in northern Mexico, and of Blackwelder[52] in central Wyoming.

DISPOSITION OF EXPORTED DUSTS FROM DESERT TRACTS

The part which exported desert dusts play in the formation of continental deposits is only beginning to receive the attention which it merits. Premising extensive wind-scour in an arid tract, the subject of the final lodgment of the fine materials removed demands adequate consideration. Of the desert dusts borne through the air the volume settling on bodies of water is doubtless very much greater than is generally surmised. Off the west and north coasts of Africa the amounts of Sahara dusts blown into the Atlantic Ocean and the Mediterranean Sea are commented on by many observers.[53] Rucker,[54] Meunier,[55] and Hellman and Meinardus[56] in particular describe certain of these dust-falls. In bays and arms of the sea, especially when situated adjacent to desert regions, accumulations of this kind must be enormous. The Gulf of

[42] Journal of Geology, vol. xvii, 1909, p. 31.
[43] Proc. Royal Geog. Soc., vol. xi, 1889, p. 648.
[44] Mem. Geol. Surv. India, vol. xxxv, 1902, p. 10.
[45] Pédologie, 1902, p. 37.
[46] Ann. Géol. Min. Russie, vol. vii, 1904, p. 43.
[47] Globus, vol. xc, 1906, p. 46.
[48] Journal of Geology, vol. xiii, 1905, p. 381.
[49] Top. and Geol. Pen. Sinai, Cairo, 1906.
[50] Top. bet. Cairo and Suez, 1907, p. 115.
[51] Eng. and Mining Jour., vol. lxxxv, 1908, p. 688.
[52] Journal of Geology, vol. vii, 1909, p. 429.
[53] Nature, vol. lxiii, 1901, p. 514.
[54] Comptes Rendus de l'Acad. des Sci., T. cxxxii, 1901, p. 894.
[55] Abhandl. K. Preuss. Meteorol. Inst., 1901, ii Bd., No. 1.
[56] Trans. American Inst. Mining Eng., vol. xl, 1909, p. 709.

California is a notable example. In the great depression to the northward, now occupied by the Mojave Desert and Death Valley, the fine Tertiary and Quaternary deposits, with thicknesses of over 4,000 to 8,000 feet, are believed to be marly dusts blown from the contiguous deserts into an old arm of the ocean.[56] The process in all its details is well shown today in the playas and "mud flats" which frequently occupy temporarily the central parts of intermont plains.

Another great but indeterminable volume of the desert dusts and sands are borne into the few large rivers which on their way to the sea from the mountains sometimes traverse the arid lands. The waters of these streams are very muddy. During the sporadic downpours of rain which occur at rare intervals large quantities of desert soil are also carried directly into these rivers by the arroyos or tributaries that for much of each year are perfectly dry.

By far the largest volume of the finer rock waste is exported through the atmosphere to regions beyond the boundaries of the desert, mainly in a direction opposite to that of the prevailing winds. The total bulk thus transported on the wings of the wind doubtless exceeds many times that removed in an equal time through the general erosion and lowering of a similar area in a normally moist or wet country. The distance to which this great bulk of the desert dust is conveyed is determined by the approach to moist climate conditions.

In the instance of the American desert region we are able to measure some of the important factors. We should expect, lying to the eastward or northeastward of the great arid tract, an extensive belt where the exported desert dusts come to rest and accumulate. In the broad semiarid area bordering the desert we should also expect to find a belt of considerable width where eolative processes are still in the ascendency, where the surface is no longer occupied by a rock-floor worn out on the beveled edges of the strata, and where eolic deposition is taking place instead of eolic removal. Still farther out we should expect to encounter a third broad belt where aëroposition is quite extensive, but where, on account of the nearness to wet climate conditions, the settled dusts are removed by the rains and the streams nearly as fast as they are deposited.

With these ideal expectations the facts observed on the Great Plains seem strictly to agree.

Abundant vegetation seems to be a most essential factor concerned in the deposition of eolic dusts on land surfaces. The thickly matted sods which cover the surface of the central belt of the Great Plains exem-

plify this essential feature, although Johnson[57] regards them as merely preventing erosion from rainfall. I have already pointed out the importance of plant growth in the formation of the loess derived from wind-blown silts along the Missouri River.[58] Shimek[59] notes the same phenomenon in connection with the Iowa loess. Huntington[60] observes that in the Kwen-Lun Mountains, on the borders of Turkestan, "wherever there is sufficient vegetation . . . the dust is held in place and heavy deposits of loess are in the process of accumulation."

In the desert itself, where deflative processes greatly predominate, cultivated areas soon become higher than the surrounding barren grounds. This is due partly to the retention of the wind-blown dusts, partly to the silts brought in by the muddy irrigation waters, and partly to the removal of the soils through deflation of the adjacent lands devoid of, or only scantily provided with, plant growth. These features are well displayed at Socorro, Las Cruces, and other old Mexican towns in the southwestern part of the United States. In the same region like phenomena are presented by many of the old Indian villages and the sites of the ancient Aztec communities. In the Lybian desert, especially in the oasis of Kharga, Beadnell[61] reports that the gardens have been raised many feet in perhaps as many centuries by the constant lodgment of wind-blown materials.

CHARACTERISTICS OF EOLIC DEPOSITS

Critical criteria for the recognition by lithologic means of wind-blown deposits have never been satisfactorily formulated. The finer and the coarser materials should be considered separately. In deserts, which are essentially areas of degradation, sands prevail, but they are ephemeral in character and seldom constitute prominent deposits except when blown directly into the sea. Accumulating mainly outside of the limits of desert areas in the semi-arid and moister regions, extensive eolic deposits are characteristically loamy. In the determination of eolic formations this distinction requires fullest attention.

Typical wind-formed deposits possess all the physical characters of the familiar loess. The most striking feature is the peculiar loamy nature already mentioned. Neither strictly clay nor strictly sand, the size of grain is intermediate. The homogeneous texture, the remarkable capac-

[57] Twenty-second Ann. Rept. U. S. Geological Survey, 1902, pt. iv, p. 637.
[58] American Jour. Sci. (4), vol. vi, 1898, p. 299.
[59] Proc. Iowa Acad. Sci., vol. iv, 1898, p. 68.
[60] Bull. Geol. Soc. America, vol. 18, 1907, p. 359.
[61] An Egyptian Oasis, 1909, p. 78.

ity as an unconsolidated mass to withstand the eroding effects of rain, the presence of unusual amounts of lime, the tendency in deposition to totally disregard existing relief features, are points which are especially noteworthy. Since there is a size below which rounding of grain can not go, the finer materials carried by the wind are apt to be somewhat more angular than the coarser sands. This is well shown by the microscope. In contradistinction to formations laid down in water, there is a marked proneness in wind-formed deposits for the flatter grains to lie in all positions, instead of all resting with broad side down.

The sands of desert regions are characterized by rounded outlines. This is probably the main distinction observable between eolic and aqueous sands. A notable factor in the reduction in size of desert sands is the rapidity of abrasion. On quartz grains, for instance, Mackie[62] has shown that with the most moderate velocities, a water current of 2 miles an hour and a wind current of 8 miles an hour, the rounding effect in air is nearly 30 times that for water. Moreover, the rounding by wind affects particles less than one-fifth the size of those abraded in water. The rapidity with which soft minerals are worn is well illustrated in the vast playa of the Hueco bolson lying beteen the Sierra San Andreas and the Sacramento Mountains, in southern New Mexico. As the shallow waters are completely evaporated each year, a thin layer of gypsum is crystallized out on the bottom of the playa. As further drying takes place the continuous layer of gypsum is cracked and broken into small pieces, which are soon moved along the surface of the ground by the winds and accumulate on the borders of the playa in vast dunes[63] of pure gypsum sands, the particles of which are all perfectly rounded, although the distance traveled has not been more than a few miles. In the same manner dunes composed entirely of rounded salt grains are formed on the borders of many saline lakes, as in the case of the Crater Salt-lake, in western Socorro County, New Mexico, and in the Laguna del Perro, on the Estancia plains, in the central part of the Territory.

The assorting power of the wind so far exceeds that of water that this feature may become an important one in the identification of eolic deposits. Quartz sands blown by the winds of the desert present remarkable purity. The soften mineral particles are quickly ground to dust and removed through the air. On the lower Volga River, during the excursions of the International Geological Congress in 1897, this circum-

[62] Trans. Edinburgh Geol. Soc., vol. vii, 1897, p. 300.
[63] Bull. Geol. Soc. America, vol. 19, 1908, p. 84.

stance was especially emphasized by some of the Russian geologists, notably by Sokolow. The same fact is noted by Walther[64] and by Udden.[65]

The calcareous nature of desert deposits is perhaps one of their most distinguishing properties. The ashen hue of adobe soils appears to be largely due to the high content of lime. In the case of the loess, the large amount of calcareous material present has always remained inexplicable. It may be that this feature may prove to be the strongest evidence of its eolic origin. That there should be such a high lime content in desert soils is not surprising. The lime is everywhere brought to the surface of the ground through capillarity, forming what in the Spanish-American States is called tepetate or caliche. In New Mexico, for example, favorable situations show beneath a few inches of pulverulent ashen soil a soft, snow-white lime-rock which often attains a thickness of 10 to 20 feet. It is frequently well exposed in railway and highway cuttings, and is encountered in other excavations. It is formed solely by the deposition of lime salts in adobe clays. As the uppermost layers of soil are removed by the winds, a large proportion of the lime materials must also be finally carried away through the air.

Red coloration, as indicating subaërial oxidation, and inferentially desert conditions under which formations possessing it were deposited, does not appear to be a very trustworthy criterion. Reds and browns are surely not characteristics of desert-formed soils. Ashen or gray everywhere prevail. My personal observations have been rather wide in the western arid country, extending from British Columbia to Guatemala; they have extended through northern Africa and around the Caspian region, but nowhere do I recall a single instance of desert deposits with red coloration due to exposure to the atmosphere. The red soils of arid regions appear to be derived entirely from old red rocks. In the dry tracts of the Great Basin the red and brown belts are invariably eruptive or very old red clastics perfectly unaffected by recent surface oxidation.

The idea of red coloration of soil as a proof of subaërial oxidation seems to apply only in moist climates. Its extension to arid areas appears unwarranted. Von Richthofen[66] was the first, I think, to call attention to the fact that in cold and in dry climates chemical decomposition of rocks is almost unknown. Russell[67] also emphasizes this point.

[64] Abahnd. d. K. Sächischen Gesellsch. d. Wissensch., xvi Bd., 1891, p. 149.

[65] Popular Science Monthly, vol. xlix, 1896, p. 655.

[66] Führer für Forschungsreisende, Berlin, 1886, p. 100.

[67] Bull. Geol. Soc. America, vol. 1, 1890, p. 134.

More recently I have treated[68] this phenomenon as it bears upon ore deposition in arid regions, and I have also described it in its relations to general deflation.[69] Recent writings of McGee on the Sonoran district of northwestern Mexico,[70] and of Passarge on the South African regions,[71] contain valuable data in corroboration of this statement.

Since redness of color is not an indication of the subaërial oxidation of desert soils, but of soils of moist climates, it can hardly be pointed to as proving desert conditions when a formation so colored was being deposited. Red rocks occurring in arid regions should, upon disintegration, quickly lose their bright coloration. Red sandstones in which the component grains are coated with films of red oxide of iron soon part with the latter through constant trituration of the grains. The fine iron oxide and red clay blow off in the dusts. The "red dust storms" of the southwestern plains come directly off the "Red Beds" tracts. "Red fogs," as described by Milne,[72] and "blood rains," which from time to time are reported in the Mediterranean region, offer strong support to this suggestion.

RELATIONS OF AREAS OF DEFLATION AND AËROPOSITION

Until lately the terranal characteristics of continental deposits have received little discriminating attention. The controlling condition enabling such formations to be preserved is that they be deposited upon a slowly sinking area, such as might be expected to exist in front of a growing mountain range. Whether the deposits be eolic or fluviatile in character, the necessary conditions are the same. Eolic depositions are likely to be extensive and remarkably homogeneous. The Great Plains region seems to afford ideal conditions. What modification the element of streams issuing from the mountain belt on the border introduces may not be measurable at the present time. Their influence, as will be seen later on, is probably small. Whatever stream materials are brought into the Plains area and deposited must so suffer at once from the effects of deflative action that they are soon converted into eolic materials in the same way that river sediments entering the sea are thenceforward marine deposits. As already stated, eolic terranes are not as a rule formed in desert tracts, but in the semi-arid and moist belts beyond.

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68 Trans. American Inst. Mining Eng., vol. xli, 1911, p. 543.

69 Bull. Geol. Soc. America, vol. 19, 1910, p. 569.

70 Bull. Geol. Soc. America, vol. 8, 1897, p. 991.

71 Zeitsch. d. deut. geol. Gesellsch., lvi Bd., 1904, Protokol, p. 196.

72 Nature, vol. xlvi, 1892, p. 128.

Eolic Significance of certain Great Plains Features

VASTNESS AND EVENNESS OF SURFACE

In the region east of the Rocky Mountains there is an expanse unbroken and a smoothness of surface that are unparalleled elsewhere on this continent. The remarkable evenness of the surface is almost perfectly developed in the median north and south belt. Eastwardly, as the region of moist climate is approached, it begins to be broken by normal stream corrasion. Westwardly, to the foot of the Cordilleras, it also is somewhat interrupted by the inequalities arising from deflative action.

The broad median belt is practically untrenched by drainage-ways. This fact is also one which Johnson[73] emphasizes in his description of the "High Plains," as he terms this belt. It seems smoother than any water-carved plain possibly can be. Its evenness is more complete than that of any known peneplain. It is more perfectly a plain than even the ideal peneplain demands. In itself this fact suggests that the surface may have been fashioned by erosional processes of a kind with which we have had as yet little to do.

With the median "High Plains" Johnson correlates the great Llano Estacado, or "Staked Plains," of Texas. The latter, as shown by Hill,[74] are a part of the broad Las Vegas plateau of New Mexico, which also finds a vast southern extension in the general plains surface of the Mexican tableland. The intermont plains of the Great Basin present, on a smaller scale, the same general aspects. In the arid plains of South Africa Passarge[75] also finds plains smoother than peneplains, astutely noting that "Wasser ist nicht imstande solche Ebene zu erodieren."

The general plains surface of the region under consideration has had a complex origin. The western part along the Rocky Mountain front is clearly a plain of deflation. It is worn out on the beveled edges of ancient hard strata. This belt is wider and the bevelment is more clearly displayed in the south in Colorado and New Mexico[76] than elsewhere. Only locally is notable aëroposition taking place. Stream aggradation is also local and unimportant. Desert-leveling is progressing as rapidly, probably, as it ever does, but it is devoloping unequally in different places. Plant growth is scant and nowhere holds down the soil.

The broad median belt of the Great Plains is one of smoothest relief.

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[73] Twenty-second Ann. Rept. U. S. Geological Survey, 1898, pt. iv.
[74] Topographical Atlas of the United States, folio 3, 1900, p. 2.
[75] Zeitsch. d. deut. geol. Gesellsch., lvi Bd., 1904, Protokol, p. 196.
[76] Journal of Geography, vol. v, 1906, p. 254.

Its surface is rather higher than the country on either side. The hard substructure is deeply covered by fine, soft materials. Its surface sustains a peculiar matted grass growth, colloquially called "sod," that not only protects it from deflative action and the sporadic corrasion of the rains, but serves to hold the dusts settling from the air. Desert-leveling is mainly of the constructive sort. The region is one of notable deposition.

East of the "High Plains" belt is a third wide tract, still constituting a part of the Great Plains region, but extending an indefinite distance until it merges completely with the prairies. It is a region far beyond the limits of the desert, but still subject to some of its effects. Aëroposition is going on at a rapid rate, yet removal of the materials thus deposited by stream corrasion is progressing almost as fast. The moist climate conditions permit the rivers to cut down into the hard pre-Tertiary rocks beneath. All eolic deposits and effects are largely disguised or obliterated. The region is one of moderately rapid degradation and the surface is now maturely dissected. Nevertheless eolic deposits are accumulating locally, the most conspicuous of which are known as loess.[77]

DISSONANCE OF STRATIFICATION

Singularly enough, the feature of the Great Plains deposits that is most characteristic of eolian deposition is the very one about which least has been said. This is the irregular, imperfect, discordant, or discontinuous sedimentation. Much as has been written concerning the geology of this region, the utter dearth of critical data upon the stratigraphy is indicated in the summary on the Neocene "Lake beds of the interior," as given in the correlation papers by Dall and Harris.[78] A single short paragraph suffices to set forth all our knowledge on the subject.

One of the most important points recently brought out concerning the so-called lake beds is the fact that in geologic age they range from Mid-Tertiary to the Present. The most complete sections of any of the beds under consideration are exposed in the *mauvaises terres* of the Missouri River region in South Dakota. As already stated, they were early noted by Evans, later described in some detail by Hayden, and named by Meek and Hayden[79] the White River group. In the subsequent tracing southward from the original locality of the White River formation its

[77] American Jour. Sci. (4), vol. vi, 1898, p. 299.
[78] Bull. 84, U. S. Geological Survey, 1892, p. 175.
[79] Proc. Acad. Nat. Sci. Philadelphia, vol. xiii, 1862, p. 433.

strictly Miocene character was lost and later formed terranes were included. In Kansas the term "Plains marls" was appropriately applied to the deposits by Hay,[80] indicating the dominating lithologic feature.

Of a maximum thickness of over 1,500 feet which the deposits display, the lower half is prevailingly sandy, while the upper half is prevailingly loamy. No other subdivisions are yet recognizable over areas of any considerable extent. It is possible that none ever will be differentiated. The alternation of fine sands and clays, the cross-bedding of the former, the abrupt transition from one to the other, the unusual frequency of unconformities, the remarkable uniformity of physical characters, in spite of the great difference in determined geologic age of the different parts, are stratigraphic points of great interest that demand adequate explanation which hitherto has been denied them.

In the comparison of the geological structure of the Great Plains with that of other desert and semi-arid plains in other parts of the world, some marked similarities as well as strong contrasts are brought out. Except in a narrow belt in the west the substructure of the region is composed chiefly of unconsolidated, more or less homogeneous deposits which are flat lying and of recent origin. In many of the great intermont plains of the Mexican tableland and of the Great Basin, of the South African plateau, of the Australian interior, and of the Russian steppes, the geologic formations are more or less completely indurated, widely different in texture and composition, tilted and folded and beveled off, and of ancient date. In the last mentioned cases the plains are now being rapidly eroded; they are areas of degradation. The Great Plains seem to be constantly adding to their volume and height.

HOMOGENEITY OF PLAINS DEPOSITS

To one accustomed only to coming in contact with the soils of moist climates, the gravelly surfaces which are often met with in desert and semi-arid areas are apt to give misleading notions of the true character of the materials beneath. Pebbles and rock debris appear to be much more abundant than they really are, because of the fact that in dry climates the finer materials are being constantly removed by the winds.[81] In the case of the Great Plains the occurrence of pebbles in profusion gives rise to the inference that they were deposited there directly through river action. Even the finest and almost pebbleless loams, with thick-

[80] Sixth Ann. Rept. Kansas Board of Agriculture, 1889, p. 92.
[81] Bull. Geol. Soc. America, vol. 19, 1908, p. 73.

ness of several hundreds of feet, frequently appear on the surface to be gravel beds.

The original determination of the supposed lacustrine origin of the Great Plains deposits rested mainly on the assumption that the prevailingly silty texture could be produced on such an extensive scale only under conditions presented by quiet lake waters. In the north, where the great through-flowing Missouri River has been able to degrade rather than aggrade its course, and where on each side the substructure is more or less deeply and sharply trenched into the "bad-lands," the marly silts, as they are commonly called, are ashen in color, remarkably uniform in texture over wide areas and throughout great thicknesses. Farther south, where the country is not cut into by rivers, deep-well borings and such outcrops as occur indicate that the deposits are still quite similar in lithologic character to the more extensively exposed *mauvaises terres.* All characteristic features continue southward and westward around the southern end of the Rocky Mountains into central New Mexico until, as shown farther on, the deposits merge completely into the undoubted desert soils and appear to be in every way identical with them.

On the other hand, in its relief features, its texture, its general appearance, and its stratigraphic characteristics the "lake deposits" of the Great Plains strikingly resemble the loess. This fact in itself is of great significance.

SIMILARITY OF PLAINS SOILS TO LOESS

Had the loess deposits of the Mississippi Valley never been called such, and had they never been compared with the deposits of the Rhine, it is probable that their genetic relations with the Plains soils would have been long since surmised. Early geologic explorers of the upper Mississippi region designated the loess as silicious marl. Between the loess and the Plains marls color alone seems to be the distinguishing feature. The genetic relations also of the ashen marls of the Plains and the thick black loams of the prairies to the eastward present many suggestive phases of great interest. They have never been critically investigated; yet there seems to be here a fertile field of inquiry. That the two may be the same geologic product appearing under somewhat different physical conditions is not at all improbable.

When, a decade and a half ago, I first set forth[82] the evidences in support of an eolian origin of the loess deposits lying along the Missouri River, I was inclined to derive all of the loess materials directly from the

[82] American Jour. Sci. (4), vol. vi, 1898, p. 299.

extensive mud flats and sand bars bordering the great stream. This source is no doubt more than ample to supply all of the necessary materials for these loess deposits as they appear today; yet it now appears probable that a considerable proportion of the fine silts, if they may be so called, actually comes from other places. Although at the present moment quantitative determinations are not available, the volume of wind-blown dusts derived from the dry upland plains to the west must be very large. The latest considerations on this point suggest that not only the contiguous country and the semi-arid belt, but the arid region also, is a large contributor to the loess of the Mississippi Valley.

The loess of the Missouri River in Iowa and Missouri owes its characteristic peculiarities to the fact that the wind-blown dusts were deposited under conditions of moist climate. Farther up the stream it gradually loses its typical aspects, assumes an ashen color, and finally becomes indistinguishable from the "bad-lands" marls. Tracing of the loess directly westward from the Missouri River in Kansas and Nebraska is difficult, because none of the larger streams are notably degrading their channels.

IDENTITY OF PLAINS DEPOSITS WITH ADOBE

On the dry Mexican tableland, where the chief building materials are sun-baked bricks, the latter are known as adobes, and the loamy soils from which they are made is called adobe. In all physical respects except the ashen color adobe is indistinguishable from the loess. Adobe is essentially wind-blown dust accumulated on the surface of the desert. Throughout the arid region of the United States its character remains constant. In the Great Basin, in the Californian Gulf basin, on the Colorado plateau, and on the Mexican tableland its features are the same, and it is everywhere easily recognizable. Unlike the soils of moist lands, adobe bears no relation to the rocks beneath.

There is, therefore, considerable genetic significance in the association of the Plains deposits and the adobe soils of the desert. The relationships between the two are not so impressive to one coming directly from a moist climate as they are in making the approach from the arid side. The similarity in physical characteristics must be more than merely coincidental. Once compared in the field, there is little hesitancy in pronouncing the adobe soil of the arid regions the same as the ashen loams of the Great Plains.

DISTRIBUTION OF COARSER DETRITAL MATERIALS

Since the Plains deposits are mainly loams throughout their great thickness, the occurrence of sands and gravels in some places in abun-

dance on the surface appears quite incongruous. Without considering the real nature of the formations as a whole, judgment based upon surface materials alone suggests river action as a possible explanation of the presence of such coarse debris. In a moist climate the observations would naturally be thus interpreted.

The coarser materials of the Great Plains deposits are best considered under the three groupings of sands, fine gravels, and pebbles including boulders. Each of the three classes are susceptible of further subdivision in treatment accordingly as they occur in the arid western belt, the semi-arid median belt, or the moist eastern belt.

Sands do not seem to play the important rôle which they are commonly assumed to do. In true desert country they are in the process of being constantly ground into dusts, so that permanent accumulation is rarely accomplished. Since the desert seldom appears as an area of notable deposition, sands are only locally and temporarily preserved. In the semi-arid belt in the so-called "sand-hills country" of Nebraska and Kansas especially, the unusual accumulation of sands seems to be dependent somewhat upon the local character of the substructure or the proximity to the through-flowing streams. At Kinsley, Kansas, for instance, the rather remarkable area of sand-dunes appears at a point where this material may be directly blown up from the Arkansas River channel. Farther eastward the eolic sands are known to extend well into the region of moist climate, even to the Mississippi River. It is a noteworthy fact that these sand ridges, or dunes, are continually moving forward, and the general advance is to the northeast. Many of them have been long known in Iowa. The latter are often several miles in length and half a mile or more in width. They destroy cultivated fields, cover up fences and buildings, until in the course of two or three years they have passed by a given spot. Bain[83] describes a rolling sand-dune of this kind in Mahaska County, Iowa, that was 30 feet high. During its passage across a certain farm it required three division fences to be built in vertical succession. These dunes are on the upland prairie surface.

The finer gravel materials which are often scattered through the desert loams appear to be partly wind-blown and partly transported by sporadic waters. On the desert the loose accumulations of small stones temporarily form the pebble pavements or pebble mosaics described by Blake,[84] by Tolman,[85] and by me.[86] The strictly wind-moved pebbles

[83] Iowa Geol. Surv., vol. iv, 1895, p. 343.
[84] Trans. American Inst. Mining Eng., vol. xxxiv, 1904, p. 161.
[85] Journal of Geology, vol. xvii, 1909, p. 149.
[86] Bull. Geol. Soc. America, vol. 19, 1908, p. 74.

are doubtless confined mainly to the arid tracts and only occur sparingly in the semi-arid belt. In the latter and in the moist region the movement of the coarser materials is accomplished almost entirely by water action.

The position of the coarser gravels along the paths of the through-flowing rivers indicates clearly that they are all of fluviatile origin.

MINGLING OF EOLIC AND AQUEOUS EFFECTS

The eastern belt of the Great Plains is of special interest at this time, because of an overlapping of both constructive and destructive effects produced by the rains on the one hand and on the other hand by the winds. This phase of the subject, however, requires especial elaboration which can not be accorded it here. One point in particular may be mentioned—the relations of the eolic deposits to the glacial drift. In the enthusiasm aroused during the past two decades in the consideration of the last, there has resulted a misinterpretation of the phenomena presented by the first.

The southern boundary of glaciation is approximately the line of the Missouri River from its headwaters to its mouth. Everywhere along the glacial margin the drift-sheet is deeply covered by loess or loess-like deposits. Although it was generally known that the latter extended forward from the edge of the drift, glacialists outside of Missouri[87] made little attempt to find out just how far such deposits occur. On the usually accepted hypothesis of glacial origin the occurrence of the so-called marginal loess has never been satisfactorily explained. Viewed as the attenuated border of an eolic intrusion from the west, which, in spite of vigorous corrasive activities, has accumulated since the retreat of the Kansan ice-sheet, adequate reason is at once found for the long puzzling peculiarities of its distribution near and without the drift area.

The important feature to note is that although eolic deposits attain vast development along the Missouri River, their true genetic character is obscured by the vigorous action of the rains, this being within the limits of moist climate conditions; it is confused by the presence of extensive glacial formations; it is easily misinterpreted because the typical deposits were never traced forward from the glacial boundary to their limits, and it is overlooked for reason that continental terranes of eolic origin have been little understood. That the real nature of the deposits in question was not deductively inferred is due largely to the circumstance that they were invariably approached from the east instead of

[87] Todd: Missouri Geol. Surv., vol. viii, 1896, p. 115.

from the west—from the side of moist climate conditions in place of from the side of aridity.

ROCK-FLOOR OF THE PLAINS ALONG ROCKY MOUNTAIN FRONT

In its general features the planation of the arid region to bedrock has been so recently considered[88] that little need be added here, except to emphasize the extent of the rock-floor immediately in front of the Cordillera. In the present connection attention should be called to the contrasts presented by this western belt of the Great Plains as an area of deflation and the median and eastern belts as tracts of eolic deposition. As an eolic product the even rock-floor worn out on the beveled strata of the substructure has particular interest and significance.

RULING GRADIENT OF PLAINS SURFACE

Penck[89] makes the observation that, provided the waters of the ocean be excluded, wind may go on indefinitely excavating the desert below sealevel. The inference is that for deflation there is no baselevel of erosion comparable to that of stream planation. More recently it has been suggested that in such case permanent groundwater-level seems soon to present conditions on account of which wind-scour can no longer act.[90]

In a desert of mountainous aspect—as the Great Basin, for example—the inclination and smoothness of the intermont plains are determined partly by the general tendency of wind-scour to form more or less even surfaces and partly by action of the sheetflood. A region of flat-lying strata—especially an area undergoing deflation in one part and aëroposition in another—is little influenced in its grading by the sheetflood. The through-flowing rivers and other waterways doubtless constitute the main factor in the determination of the gradient of the general surface. These features are brought out in another connection.

Objections to the Lacustrine Theory

At this time and distance it is hardly necessary to state at length the shortcomings of the hypothesis of a lake origin of the Great Plains deposits. Insuperable seem to be the vastness of the lake conditions required, the absence of any known eastern barriers, the want of distinct shorelines, the presence of interbedded coarse formations, the vague

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[88] Bull. Geol. Soc. America, vol. 19, 1908, p. 63.
[89] American Jour. Sci. (4), vol. xix, 1905, p. 167.
[90] Journal of Geology, vol. xvii, 1909, p. 659.

stratification presented by the fine deposits, the prevalency of remains of large land animals and an entire absence of fish and aquatic invertebrate fossils, the complete merging of the terranes on the one hand into undoubted eolic deposits and on the other hand into unquestionable river formations, and the existence of climatic conditions precluding the development of extensive bodies of quiet waters.

Weakness of the Fluviatile Hypothesis

The origin of the Great Plains deposits through means of the aggrading action of rivers is urged mainly because of (1) the well known building up process of certain streams in a sinking area; (2) the vast and even surface of many fluviatile plains; (3) the presence of a great mountain background capable of supplying enormous quantities of rock-waste; (4) the capacity of rivers to form extensive deposits of fine texture and even stratification; (5) the importance of coarse piedmont deposits in dry mountainous regions; (6) the frequent evidences of subaërial exposure throughout the terranes, and (7) the resemblances of river deposits to those of the great intermont basins of arid lands. These several features may be briefly considered. In so far as the Great Plains are concerned, I am inclined to agree with Davis that the consideration of the fluviatile aspects of their origin has been not so much directed toward the actual observation of facts in the Rocky Mountain region as toward the theoretical discussion of recorded observations. Nevertheless, this discussion is of the highest benefit.

Since after debouching from the desert ranges torrential streams soon wither away, it is generally assumed that their loads of rock-waste are at once dropped, and that piedmont plains are rapidly built up. The idea is well expressed by Huntington[91] when he speaks of southern Arizona "mountain ranges half smothered in interminable slopes of gravel which head far up on the flank of the hills and sometimes cover the passes." The extension of this local conception to a broad generalization embracing, for example, so vast an area as the plains east of the Rocky Mountains, seems but a step. Deductively great importance is attached to the aggrading action of streams.

In the Great Basin region, where excessive dryness prevails, the intermont plains appear not to be so deeply covered by mountain waste as was once supposed. There are now known many cases in which beneath a veneer of soil and rock debris such plains have well defined rock-floors.[92]

[91] Harper's Magazine, vol. cxxiii, 1911, p. 54.
[92] Bull. Geol. Soc. America, vol. 19, 1908, p. 69.

Many of the desert ranges display another peculiarity. The streamways do not always continue directly out on the adjoining plain until their sporadic waters sink out of sight. On one side of the range, and sometimes on both sides, these drainageways, soon after leaving their canyon mouths, enter a master stream, the course of which is in a direction parallel to the mountain axis. When they appear torrential waters are not carried forward as might be expected, but are diverted toward one end of the range or the other, there to enter a through-flowing river. In illustration, the Sandia and Manzano ranges, east of Albuquerque, New Mexico, may be cited; not a drop of water falling on these mountains reaches the Estancia plains to the eastward. In the lofty Sierra de los Caballos, which forms the western border of the broad Jornada del Muerto, in southern New Mexico, canyons at the foot of the eastern slope do not permit a single waterway to drain out onto that vast plain. In the Funeral range, in Nevada, the same conditions prevail. Many more instances might be mentioned. The principle involved is especially applicable to the Great Plains along the Rocky Mountain front.

At the base of the Cordillera, in Colorado, the railroads traverse the entire breadth of the State in a deep north and south valley. The ridge formed on the east side of this valley is not a range of foothills genetically related to the mountains, but is merely the western margin of the Great Plains surface. Within the limits of Colorado this ridge is broken by streams only at two points. The Platte and the Arkansas rivers are the only streams rising in the Rocky Mountains that pass into the Plains region. This fact is still more noteworthy when it is remembered that in all the great distance between the Canadian and Mexican boundaries the waters of only five rivers whose headwaters are in the Rockies become streams of the Great Plains. Contrary to general opinion, the Cordilleran-born streams, with the five exceptions mentioned, debouch not upon the Plains.

No matter how favorable otherwise are the conditions in the Great plains region for extensive stream aggradation, the meager number of rivers actually present are manifestly so vastly inadequate for the work that there arises at once the query as to how much of the aggradation hypothesis could have been based upon direct observation. Evidences of unquestionable river action of a constructive character appear only in the immediate vicinity of the few through-flowing streams already mentioned. Nowhere in the country between these rivers have I noted any indications whatever of deposits that could possibly be ascribed to fluviatile influences.

The comparison of the vast and even surface of the Great Plains with that formed by certain great rivers—as the Po, the Ganges, or the Hwang-ho—appear to afford evidences strongly against rather than in support of the hypothesis. In the last mentioned cases it is the mouths of the rivers that are considered. In the Great Plains area it is really the headwaters of the streams that are taken into account. Clearly there can not be any valid comparison. The tendency of rivers to form extensive deposits of fine texture and even stratification appertains to their lower reaches and not to their sources.

A lofty mountain background capable of supplying enormous amounts of rock-waste seems to be afforded on a grand scale by the Rockies. In moist climates generally, and with similar features, such supplies of coarse materials are usually at hand. Even the coarse piedmont deposits in many desert regions are important. The case of the Great Plains is not in accord with such rule. So far as personal observation goes, and so far as the most trustworthy literature indicates, coarse piedmont deposits do not extend forward everywhere along the Rocky Mountain front. Deposits of fine homogeneous materials of the nature of loess begin to appear on the great piedmont, and extend in enormous volume indefinitely eastward. Coarse materials are generally wanting. Only along two streams in Kansas and Nebraska, for instance, do coarse materials appear beyond the piedmont belt.

Recapitulation

From the foregoing record of observations and the consideration of the Great Plains, it is argued that—

(1) The dominant relief feature is to be regarded as fashioned mainly by eolative processes, and as infinitely smoother than it is possible to attain through planation effects of water action.

(2) The Plains deposits are chiefly wind-borne dusts derived from the deflation of the arid regions, and extend in full force to the Missouri River.

(3) Eolation, both of destructive and constructive character, is still in progress on a large scale, deflation prevailing in a broad western belt, aëroposition predominating in the wide median belt, while in the eastern belt extensive eolic deposition is greatly obscured by the conditions presented by moist climate.

(4) To a surprising extent are fluviatile activities inconsequential, while lacustrine influence has been practically *nil*.

(5) There is no genetic relationship existing between the drift-sheets and the deposits of loess along the Missouri River, the materials of the first mentioned being derived from the northeast and those of the last named from the wind-borne dusts of the west.

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ABSTRACTS OF PAPERS PRESENTED AT THE TWENTY-THIRD ANNUAL MEETING OF THE SOCIETY, BUT NOT PUBLISHED IN FULL IN THE PRECEDING PAGES OF THIS VOLUME, TOGETHER WITH DISCUSSIONS OF PAPERS AS FAR AS PRESERVED.

E. O. HOVEY, *Secretary*

CONTENTS

LIST OF UNDERGROUND TEMPERATURES IN THE UNITED STATES

BY N. H. DARTON

(*Abstract*)

This list includes data collected during the past fifteen years by the author and his associates in various portions of the United States. Several hundred observations have been made in deep borings with a self-recording thermometer of special type. All other available data have been compiled to make the list as complete as possible. The rate of temperature increase has been found to be very variable, but in places there is a marked relation to geologic features.

UNUSUAL DISTORTION OF THE LOWER KITTANNING COAL

BY RICHARD R. HICE

(*Abstract*)

Of the whole Allegheny series in western Pennsylvania, no horizon is more regular and continuous than the Lower Kittanning coal; indeed, with its ac-

companying clay, it is one of the best keys of the series. While there are many changes and local variations in the sandstones and shales, caused in many cases by distinct erosion intervals, this coal, while not always workable, is uniformly found over a large area. It is not marked by distinct foldings or distortions, but by parallelism with both the under and overlying strata. At the site of Dam No. 5, on the Ohio River, on the eastern edge of the Beaver Quadrangle, between the towns of Rochester and Freedom, a recent railroad cut exposes, in a distance of some 600 feet, a series of foldings involving the strata between the base of the Lower Kittanning clay and the horizon of the Middle (Upper) Kittanning coal (about 35 feet), in no way involving the underlying strata or those above the horizon of the Middle Kittanning coal.

FURTHER EVIDENCE OF AN UNCONFORMITY IN THE SO-CALLED LARAMIE OF THE RATON COAL FIELD, NEW MEXICO

BY WILLIS THOMAS LEE

(*Abstract*)

During the summer of 1910 a critical examination was made of the unconformity in the coal-bearing rocks of the Raton coal field, New Mexico, which was announced in a paper read before the Geological Society of America two years ago, and the investigation was extended throughout the Raton Mesa region. The line of unconformity was followed, and the structural relations of the two coal-bearing formations were examined at points separated by short distances. Additional evidence was obtained of a time break between these formations. The lower one is variable in thickness, and in order to show this variation columnar sections were measured along the outcrop in the steep sides of the mesas. These indicate that the ancient surface represented by the unconformity was an undulating plain, and an inspection of the bedding, together with the character of the basal conglomerate of the upper formation, proves that this plain was one of erosion. Data were collected that indicate in a general way the amount of this erosion, and fossils were collected that will establish the geologic age of the two coal-bearing formations.

REPEATING PATTERNS IN THE RELIEF AND IN THE STRUCTURE OF THE LAND

BY WILLIAM HERBERT HOBBS

Published as pages 123-176 of this volume.

Discussion

Prof. W. M. Davis presented some objections to the sweeping application of the control of drainage courses by joint systems, and suggested that chance agreements may have a larger value than is given to them by Professor Hobbs. The structure is always recognized by physiographers as in one way or another exerting control on processes of surface sculpture, and if physiographers have given small value to joints as guides to stream courses, it is because they believe that joints are in many cases not of much importance in that connection, although in special localities their importance is undeniable.

Professor HOBBS replied as follows: This criticism of Professor Davis is already somewhat familiar, and of course is the first question which arises in certain kinds of joint studies. The investigation which is here reported is made along a line wholly neglected by the New England School of Geomorphology which Professor Davis has founded. Since, however, it is concerned with the lines of special excavation by eroding agencies, its importance is of the first rank in geomorphologic studies.

Prof. J. F. KEMP: I am convinced that there is much truth in the feature as presented by Professor Hobbs. All of us who have worked in the Adirondacks have been impressed with the marked system of northeast and northwest precipitous escarpments and valleys, and in the eastern mountains with an older north and south and east and west series whose sides show more protracted erosion. The map used by Professor Hobbs from the southwestern corner of the Elizabethtown sheet is a striking illustration. The drainage relations were first emphasized by Professor Brigham, who called the system "trellised drainage." We have since shown the dependence of the streams upon faults.

APPARENT SUN-CRACK STRUCTURE IN DIABASE

BY EDGAR T. WHERRY[1]

(*Abstract*)

The upper surface of the great diabase sill of the Newark Group, in Montgomery County, Pennsylvania, shows at several points a network of lines closely simulating sun-cracks. Thin-sections show these lines to consist of streaks of coarsely crystallized augite and feldspar traversing the fine grained groundmass. They are probably to be regarded as shrinkage cracks developed by the sudden cooling of the molten diabase against the shale surface, filled up by molten material from the interior of the mass. Boulders of weathering have also been observed showing hexagonally arranged cracks, but these are entirely of secondary origin, no structural peculiarity being observable in connection with them.

DISCUSSION

Dr. G. W. STOSE: This same phenomenon has been seen on the upper contact surfaces of diabase sheets in southern Pennsylvania, and is regarded as produced by shrinkage on rapid cooling and incipient formation of polygonal blocks.

GEOLOGY OF PART OF LUNA COUNTY, NEW MEXICO

BY N. H. DARTON

(*Abstract*)

During the past autumn an examination was made of the structure of the Cooks Peak Range, Florida Mountains, and some adjoining ridges in southwestern New Mexico. They present an extensive sedimentary succession and a series of varied igneous rocks. The structural features throw considerable light on the character of desert ranges. The great bolsons, separating the

[1] Introduced by Benjamin L. Miller.

mountains, are underlain by a thick deposit of unconsolidated deposits containing water under novel conditions.

PRE-CAMBRIAN OF SWEDEN, WITH COMMENTS ON AMERICAN TAXONOMIC PARALLELS

BY JAMES F. KEMP

(*Abstract*)

The excursions in connection with the Eleventh International Geological Congress afforded exceptional opportunities for observing the Swedish pre-Cambrian, and for becoming acquainted with the local workers and their results. From these three sources a sketch has been prepared, with the purpose of describing the larger features and of running some parallels with America.

Discussion

Dr. J. M. Clarke: What is the interpretation of the occurrence of anthracitic carbon?

Professor Kemp replied as follows: In the papers consulted on the geology of Finland in the preparation of the paper just read, only brief mention of these beds was made, but they are doubtless more fully discussed in the memoirs of the Finland Survey. They lay outside the excursions of the Congress. It would seem that they must be interpreted either as old petroleum asphalt deposits of inorganic origin or as accumulated carbonaceous matter of organic source. The latter explanation would push life farther back on the earth than has generally been thought possible.

Prof. H. P. Cushing called attention to the general similarities of all districts of the older rocks when studied.

Professor Kemp spoke as follows regarding the definition and origin of skarn: Associated with many bodies of magnetite in Sweden are masses of dark basic minerals, hornblende, pyroxene, and biotite, which are called skarn. They are believed to be basic segregations of silicates which accompanied the separation of the magnetite in the differentiation of an igneous magma. They are very marked at Gellivare, and appear also in northern Sweden in association with those magnetite ore bodies which are attributed to differentiation.

Prof. W. G. Miller: The geologists from America were struck by the strong resemblance of the Swedish pre-Cambrian to that of the Lake Superior, Huron, and other regions. The oldest series of the Kiruna district, the soda-greenstone, can not be distinguished in the field from the oldest series, the Keewatin, of the Lake Superior ranges. The soda-greenstone is overlain by conglomerate similar to the Huronian.

CHAZY FORMATION IN THE OTTAWA VALLEY

BY PERCY E. RAYMOND

(*Abstract*)

The Chazy formation in Canada as defined in the "Geology of Canada," 1863, consists of two portions, each with a maximum thickness of about 150

feet. The lower portion is chiefly sandstone and shale; the upper, limestone. Work done recently shows that there is an abrupt change of fauna at the top of the lower portion as thus defined, and that only the lower portion belongs to the Chazy (Upper Chazy). The upper portion contains two members, the lower of which is apparently to be correlated with the Pamelia limestone of New York and the upper with the Lowville. If these correlations are correct, then the Frontenac axis was not effective as a barrier after the close of Chazy time, and the Pamelia is younger than the Chazy, instead of being equivalent to the lower part of the Upper Chazy.

FRANKFORT AND UTICA SHALES OF THE MOHAWK VALLEY

BY RUDOLF RUEDEMANN

(Abstract)

The Utica shale of the Lower Mohawk Valley consists of two divisions. The lower one of these (Canajoharie shale) is of Upper Trenton age. It thins out rapidly westward and is absent at Utica. The typical Utica shale somewhat changes its faunal character eastward. The Frankfort shale thickens enormously eastward, also becoming coarser and indicative of near-shore conditions. It has furnished a considerable fauna (among others a new eurypterid fauna of eleven species), which proves it to be a later development of the Utica and not of Lorraine time. It is also divisible into two stages, the upper one (Indian Ladder beds) carrying a different fauna and being present only in the east.

STRATIGRAPHY OF THE LOWER PENNSYLVANIAN OF NORTHEASTERN OKLAHOMA

BY D. W. OHERN[2]

(Abstract)

The area discussed lies between the Kansas line on the north and the Arkansas River on the south; and between western limit of the Boone chert on the east and the 96th meridian on the west. Over the entire region, embracing some 3,700 square miles, the rocks dip gently westward. Shales predominate, becoming arenaceous toward the Arkansas River. Limestones thin and sandstones thicken southward. The whole series is between 1,500 and 2,000 feet or more in thickness.

The following formations have been established, beginning with the oldest:

	Feet.
Vinita formation, shales, sandstones, limestone lentils.....	450 to 1,200
Claremore formation, three limestones and two intervening shales	100
Labette shale	150
Oolagah formation, limestone split by a shale lentil to northward	100
Nowata shale, containing at least one bed of coal..........	50 to 100

[2] Introduced by C. N. Gould.

Above the Nowata shale different formational limits are necessary for the northern and southern parts of the region.

Northern part:

	Feet.
Lenapah limestone	20
Curl formation, shales, sandstones, and thin beds of coal	250

Wann formation, embracing:

Hogshooter limestone member	10
Copan member, shale, sandstone, and two limestone lentils	250
Stanton limestone member	8

Southern part:

Skiatook shale	500
Ramona formation, two limestones, and an intervening clastic bed	100

The limestones usually abound in remains of marine organisms. There is a dearth of fossils in the clastic beds.

The thinning of limestones and shales, the thickening of sandstones and of the entire series, to the southward, points to a former land area in that direction.

SKETCH OF THE LOCAL GEOLOGY, CITY OF PITTSBURGH

BY PERCY E. RAYMOND

(*Abstract*)

The city is situated along deep trenches cut by the present rivers and in abandoned valleys of pre-Glacial streams. Both were cut in a nearly level plateau, whose surface is from 500 to 600 feet above the present water level. Terraces and river gravels are well exhibited at many places along the abandoned valleys.

The strata underlying the city are of middle and late Pennsylvanian age, almost the whole of the Conemaugh and Monongahela series being well exposed. The nearly continuous exposures along the rivers afford an excellent opportunity for tracing the various beds, and many interesting changes in sedimentation, including erosional unconformities, may be seen.

Discussion

Mr. E. W. Shaw: The high terraces and abandoned valleys of western Pennsylvania are gravel-covered rock shelves lying 200 feet or so above present stream channels. Their impressiveness is attested by the long list of names of eminent men who have studied and described parts of them. The features have been ascribed to submergence and marine erosion, to a large ice dam at Cincinnati or Beaver, to normal stream-work, and to huge local dams of ice. At the Boston meeting, last year, I presented a paper in which I attempted to show that the high terraces and abandoned valleys, instead of being due to any of the above causes, developed as a unit through the overloading of the Allegheny in early Glacial time. I hope that within a few months my paper on this subject will appear in the Journal of Geology. At present I can not take time to present the evidence, but in brief the view is as follows: The

aggradation of the Allegheny caused every tributary, including the Monongahela, to aggrade, and the coarseness, limited upstream extent, slope, and other characters of the tributary deposits indicate that those streams built up as rapidly as the overloaded master stream. As each stream bed rose, it reached the height of one after another of the low places in divides between small tributaries, and at such times and places the currents of the rivers were divided and the cols occupied. When final readjustment began, the rivers chose the channels momentarily most desirable, and thus many parts of valleys were abandoned. The network of abandoned valleys near Pittsburgh is looked on as a result of the processes above outlined. Some of the courses are broad and were used for a long time, and others were only temporarily occupied. It will be seen that the time represented by the abandoned valleys and their deposits is far longer than that represented by the inner gorges. The high terrace deposits are looked upon as probably Kansan in age, but the processes of abandoning and partially filling the valleys lasted long enough for at least two well developed valleys, such as we find here and at Belle Vernon, to have been developed side by side. These old valleys are considerably broader than the inner gorges through which the rivers flow today; hence we must conclude either that Kansan time was much longer than all the time that has elapsed since, or else—the more likely inference—that the development and partial filling of valleys now abandoned progressed not only through Kansan time, but other epochs.

CRETACEOUS AND TERTIARY FORMATIONS OF WESTERN NORTH DAKOTA AND EASTERN MONTANA

BY A. G. LEONARD

(Abstract)

The formations occurring in the region under discussion are the Pierre shales, Fox Hills sandstone, Lance formation (Ceratops beds), Fort Union, and Oligocene. The Pierre and Fox Hills, which are marine formations, are found along the Missouri River and its tributaries. The Lance formation covers a large area in south-central North Dakota, where it has a thickness of 600 to 700 feet, and occurs also on the Little Missouri, Yellowstone, and Missouri rivers. It is composed of shales and sandstones, the upper hundred feet being a massive, yellow sandstone. Overlying the Lance formation is the Fort Union, which contains most of the coal of the region. It is readily distinguished from the Lance formation by its light yellow and ash gray color, as well as by its fossils. The Oligocene beds are restricted to a few small areas in North Dakota and southeastern Montana.

EOCENE AND OLIGOCENE OF THE WIND RIVER AND BIG HORN BASINS

BY WILLIAM J. SINCLAIR AND WALTER GRANGER

(Abstract)

Conformable superposition of Wind River on Wasatch and unconformable Lower Oligocene on Uinta-Bridger-Lower Eocene have recently been found in the Big Horn and Wind River basins, respectively, in northwestern Wyoming.

These structural depressions, partly inclosed by the Big Horn, Bridger-Owl Creek and Wind River Mountains, were receiving sediments during the Lower Eocene and Lower Oligocene, but since then have been subjected to deep dissection by streams and wind erosion, exposing sections of the Tertiary filling.

Non-volcanic sediments predominate in these Tertiary beds, derived in large part from the rocks of the surrounding mountains, shown by the abundant granite, gneiss, and sandstone fragments in the channel sandstones interstratified with the alternately banded red and blue or yellow clays of the Wasatch and Wind River and by the presence of arkoses in the Uinta. Explosive volcanic eruptions are indicated by a few narrow tuff bands in the Eocene (Wind River), but especially by a great flow of andesitic agglomerate in the Lower Oligocene. Fine, wind-blown silts, highly calcareous marls, and siliceous spring deposits (chalcedony and opal) characterize the Oligocene above the horizon of the volcanic mud flow.

Suggestions are offered in explanation of the alternation of color bands in the Eocene clays, based on lithologic and paleontological data.

Early Tertiary orogenic movements, involving renewed uplift of the Big Horn arch, are demonstrated by a great marginal anticline found in the Wasatch and by the numerous sandstone dikes, apparently of seismic origin, contemporaneous with the accumulation of the Wasatch clays.

Discussion

Mr. Sinclair replied as follows to a question by Mr. Campbell: The Wind River deposits in the Bighorn Basin (about 325 feet in thickness, so far as now known) overlie the Wasatch with perfect stratigraphic conformity. Their age is definitely determined to be Wind River by the presence of *Lambdotherium*, showing that they are to be correlated with that portion of the typical Wind River east of Lost Cabin, which contains the characteristic *Lambdotherium* fauna.

TWENTY-FOOT TERRACE AND SEA-CLIFF OF THE LOWER SAINT LAWRENCE

BY JAMES WALTER GOLDTHWAIT

(*Abstract*)

Among the raised beaches of the Saint Lawrence Valley investigated by the Canadian Geological Survey last summer is a great terrace and sea-cliff, not hitherto described. It is unique for its topographic strength and continuity. The terrace has been traced over 200 miles eastward from Quebec and found to maintain a fairly uniform altitude of 20 feet above sealevel. It is believed to be of wide extent. The question is considered whether it records (*a*) a prolonged halt between two upward movements of the coast since the great "Champlain" submergence; or (*b*) coastal subsidence of long duration, separating an earlier emergence, which was rapid and of great magnitude, from a later emergence, which was slow and of relatively slight amount. Correlation with other evidences of post-Glacial subsidence is discussed. The threefold division of post-Glacial time in Scandinavia by Brögger and de Geer is cited as a parallel case, and the bearing of these facts on isostacy is suggested.

Discussion

Dr. F. B. Taylor: It seems to me that one of the most important points brought out by Professor Goldthwait is the attitude of his highest marine beach and the sources suggested for its isobases. This beach appears to be continuous with Gilbert's Oswego beach. It seems to descend from the vicinity of Covey Hill both to the northeast and to the southwest, as though crossing the axis of an anticline extending northwest and southeast. Present knowledge of this beach in the basin of Lake Champlain, partly from Woodworth's observations and partly from my own, suggests that this anticline pitches downward to the southeast, and hence that the isobases bend around across it through something near 180 degrees. The deformed planes of the old beaches of the Great Lake and Winnipeg basins seem to suggest that this anticline may extend to a point at least 50 or 100 miles beyond the northwest corner of Manitoba or half way across the continent from the Atlantic to the Arctic Ocean.

Professor Goldthwait replied as follows: The isobases shown on the map for the deformation of the highest marine beach are based on data from several sources. Instrumental measurements of altitude of the beach at two localities on the north side of the St. Lawrence River show that east of Quebec the isobases cross the river nearly at a right angle.

PRE-GLACIAL COURSE OF THE UPPER HUDSON RIVER

BY WILLIAM J. MILLER

Published as pages 177-186 of this volume.

Discussion

Prof. J. F. Kemp: The character of the topography in the Lake George Valley has some bearing on the question. Lake George consists of three parts: a southern portion of relatively mature topography; a middle, narrow, filled with islands, and having very precipitous mountainous sides, and a northern, with more mature topography again. I have long thought that there were two pre-Glacial valleys, one draining south and one north, with a divide between. For several years, partly with the help of friends and partly in person, I have been accumulating soundings in Lake George, and have the southern two-thirds completed. In the deeper parts the bottom ranges about 90 to 100 feet. The greatest depth is near the east shore east of Bolton Landing, and is 175 feet. Doubtless the lake valley is largely drift-filled, and we can not state the depth of the bedrock, but when the soundings are completed at the northern end we can draw the profiles and make some estimates. The depth of the bedrock concerns the old drainage relations in an important way.

Prof. H. L. Fairchild: For considerable time during the waning of the ice-tongue in the Hudson Valley, the ice must have blocked the present channels of the upper Hudson and of the Sacandaga rivers, and have caused a ponding of the waters in those valleys with a broad lake at Northville. The only possible escape for the waters during this episode was southward into the Mohawk

Valley. The fact of standing water over Northville has been recognized by Professor Brigham, and the lake is mapped and described by myself in an unpublished bulletin of the New York State Museum.

MOHAWK GLACIAL LOBE

BY ALBERT PERRY BRIGHAM

(*Abstract*)

The limits of the Mohawk glacier; relation to glaciers of the Adirondacks, Catskills, Hudson Valley, and central New York; character and extent of topographic changes due to ice-work; mode of retirement of the ice; water-laid formations and glacial lakes; drainage modifications of the Hudson and Sacandaga rivers.

Discussion

Professor Brigham replied as follows to a question by Professor Fairchild: Two critical localities were observed with care. A few miles north of the head of Otsego Lake there is no sign of cutting at the watershed, which is between Springfield Center and Vanhornesville. In fact, low hills with morainic contours, unmarred by later changes, pass completely across the valley at the point of divide. There is no cutting on the Delanson col, which is floored with till, bearing many angular and unwashed fragments of the drift. There are no marks of wave action on the slopes westward to Esperance Station. There are no indications of a large outlet stream at Duane Station or down the gorge of the Boxen Kill. This gorge in its lower part is strongly developed, but it is excavated in shales and is nicely adjusted to the vigorous stream which is now at work. Its tributary gorges also, which could have carried no Mohawk waters, are comparable to the main gorge in their development. Farther up the Boxen Kill, frail morainic hills still extend down to the stream in a position in which a greatly enlarged current must have eroded their streamward slopes.

Prof. Lawrence Martin: Are there recessional moraines laid down in the waters of marginal glacial lakes? Are they weaker than the other moraines?

Professor Brigham replied: No water-laid or other moraines were seen which would correlate with waters having an outflow across the Delanson col. In fact, the central and southern parts of the Amsterdam and Fonda quadrangles are exceptionally free from morainic accumulations.

In a paper presented hastily at the Baltimore meeting and not yet published, I showed how the Adirondacks at one stage in the waning of the ice-sheet had become partially uncovered and stood as an island, so to speak, in the sea of ice. The waters from the melting of the inclosing ice produced high-level lakes in the Adirondack valleys, which accounts for the elevated and extensive sand-plains encountered in the Adirondacks. These waters of the Adirondack stage had no escape except southward across the strait of ice in the Mohawk Valley to Susquehanna drainage. Some peculiar features of ancient stream-work at the head of the Otsego Valley are attributed to this overflow. During the Adirondack stage of the glacial waters an extension of the Hudson ice lobe pushed westward up the Mohawk Valley, as indicated by the striæ on Professor Brigham's map, and produced a group of excellent

drumlins north and northwest of Richfield Springs. This westward flow of the Hudson-Mohawk ice was opposed by an eastward flow of the ice in the Ontario basin. At a later stage an ice-free space was left between the two opposing lobes, and the glacial waters then held in the Mohawk Valley I have called the Herkimer Lake, which had its first outlet at Summit Lake, and later at Cedarvale, to the Susquehanna. As the depth of ice lessened in the Champlain-Hudson Valley, the Mohawk lobation shortened and the Mohawk glacial waters spread eastward and found escape along the face of the Helderberg scarp, and at a lower stage through the pass at Delanson. These eastward-escaping waters are named the Schoharie Lake.

LAKE MAUMEE, IN OHIO

BY FRANK CARNEY

(*Abstract*)

A detailed study, during the past summer, of the Mentor, Chardon, Perry, Ashtabula, and Conneaut quadrangles raises a question as to this glacial lake extending east of the Euclid topographic sheet. The widely disconnected gravel and sand areas and weak terraces appear to be the work of local ice-front bodies of water and of ice-front streams, instead of an eastern extension of Lake Maumee, as heretofore suggested.

Discussion

Mr. F. B. Taylor: I accompanied Mr. Leverett, in 1899, in an effort to trace the Maumee beaches to an end eastward from Cleveland. The results are published in Monograph XLI, United States Geological Survey, and I am sure that a careful reading of his description will show that he discriminated closely between river-made features of ice-border drainage and wave-made features of the old lake shores. The terrace at the Garfield monument appears to be the delta deposit of a river coming from the northeast along the front of the ice, and the scoured bed of this river was observed farther toward the northeast. The bed of the river descends slightly toward the southwest, and the terrace is above the level of the Maumee beaches. Beach fragments corresponding to the second Maumee beach were found at frequent intervals as far as Girard, Pennsylvania, and their height above the Belmore or Whittlesey beach, next below, was carefully noted and found to be uniform, showing no appreciable rise as far as Girard. Most of the beach fragments were rather faint, but often quite distinct, as I remember them. Our interpretation of these fragments as representing the second Maumee beach seemed to be strongly confirmed by their horizontality when compared with the much stronger Belmore beach below. As I recall Mr. Leverett's statement, he found no certain evidence of the upper Maumee beach east of Euclid, all the distinct shore features above the Belmore and east of Euclid belonging apparently to the second beach of Lake Maumee. I am inclined, therefore, to believe that Professor Carney has missed the faint forms of this beach east of Euclid.

STUDY OF ICE-SHEET EROSION AND DEPOSITION IN THE REGION OF THE GREAT LAKES

BY FRANK BURSLEY TAYLOR

(*Abstract*)

The paper describes:

(1) The distribution of the drift with reference to its thickness in the southern peninsula of Michigan in some detail and in adjacent and more distant parts of the Great Lakes region in less detail.

(2) The disposition of the larger thick and thin areas with reference to the major elements of topography, and also with reference to the direction of ice-movement and the principal currents and eddies of the ice-sheet.

(3) Erosion by the ice-sheet in several limited localities is described, some representing maximum, others medium, and still others minimum effects, and the relation of these effects to the major features of topography and to the principal ice currents and eddies are discussed. The conclusions thus reached are generalized and extended to larger areas and to the region as a whole.

(4) The effects of the marginal oscillations of the last ice-sheet upon the deposition of its drift, as modified by the arrangement of the principal currents and eddies of the ice-sheet and the larger element of land relief, are discussed.

(5) The conclusion is reached that erosion by the ice-sheet in the region of the Great Lakes was extremely small, except on materials already weathered and loosened. In the great belt of thick drift, lying principally south of the Great Lakes, deposition predominated for the greater part of the time, and erosion was almost nil. Maximum erosion effects occur on overridden reefs in the path of the principal currents. Maximum deposition effects occur in eddy areas behind large obstructing masses, along eddy lines between the greater currents, and in the great thick drift belt where marginal lobes were spreading and unloading and where the number of oscillatory readvances was greatest.

(6) The further conclusion is reached that the Great Lakes basins were not scooped out by the ice-sheet, and that effects of deepening and widening by ice-sheet erosion are quite local and are offset or overbalanced by shallowing and narrowing by deposition in other parts, which are described.

(7) The reason for the lightness of ice-sheet erosion in the Great Lakes region as compared with that in Alpine and fiord valleys is (*a*) lack of concentration and long maintenance of flow in narrow chutelike courses, and (*b*) lack of the steep declivity requisite for a relatively high velocity of flow. There was nothing in the Great Lakes region resembling the conditions which attend the making of fiords or overdeepened Alpine valleys, where erosion by ice finds maximum efficiency and power.

(8) The valleys of the Finger Lakes are not analogous to fiords, but are indentations in the infacing rim of a basin from which the ice moved toward and over the rim, and have not been made or notably deepened by the ice-sheets.

(9) The main conclusions reached agree with those of Fairchild, namely, that in the region of the Great Lakes ice erosion of unweathered rock was extremely slight, but they do not agree with the broader generalization implied

in the title of Fairchild's paper ("Glacial erosion a fallacy"). The paper aims to set forth the differences of conditions which caused the deep erosion of Alpine valleys and the slight erosion of the Great Lakes basins.

Discussion

Dr. C. A. Davis: In the course of some years' work for the Michigan Survey, many cases of slight glacial erosion in the direct lines of ice-movement, as shown by striæ, etcetera, were discovered. In several cases apparent deep grooving and scratching were found on examination to be due to the cleaning out of weathered joint and other similar cracks, even when the eroded material was soft schist. In one locality in the northern peninsula of Michigan, staurolite crystals included in a schist were weathered out of the schist preglacially, and had been passed over so lightly that, although the direction of ice-movement could be determined by the clear-cut striæ on the truncated surface of the crystals down to the general surface of the rock only a half inch below, the freshness of the striæ on the crystals and the well known resistance of the schist to weathering preclude the hypothesis that the weathering is post-glacial.

Prof. R. D. Salisbury: The phenomena cited by Mr. Taylor are interesting as an illustration of the position which his paper sets forth—namely, inefficiency of ice erosion in much of the lower peninsula of Michigan—but I think it would be easy to assemble phenomena from other parts of the broader region of which this peninsula is part which point with equal clearness to the opposite conclusion. This leads to the general comment that the ice seems to have acted very differently in different places, and that while the phenomena of some areas seem to indicate inefficiency of glacial erosion just there, the phenomena of other areas indicate with equal clearness efficiency of glacial erosion. The general fact that in the broad region of which the lower peninsula of Michigan may be said to be a part the great body of drift is made up of fresh, unweathered rock material, much of which has been transported but a short distance, seems to me to be a final argument against inefficiency of ice erosion in these latitudes.

Dr. J. B. Tyrrell: I am very much interested in the remarks which have just been presented by Mr. Taylor, and I would like to say a word on the probable amount of material that was swept from northern Canada by the glaciers of the different Glacial periods.

To begin with, it is quite clear that all the decomposed rock which existed on or covered the hard rocks of northern Canada in pre-Pleistocene times was cleared off and carried away by one of the ice-sheets, and probably by the first one.

At the present time there are very few places in the north which show the amount of decomposed material which covered the rocks, but there is one place—namely, in the Klondike district of the Yukon territory—which was not overridden by the ice-sheet of the Glacial period, and which, therefore, shows the normal conditions of weathering on the surface.

In that district the rock in the bottoms of the valleys is more or less fresh and undecomposed, but on the higher parts of the hills these rocks, often biotite schists, similar to those so common in northern Ontario, are weathered

and decomposed to considerable depths, so that I have seen a shaft sunk to a depth of 60 feet in the decomposed rock with pick and shovel alone after the frost has been driven out by heat. We might, therefore, confidently expect that the schists and granites of other portions of northern Canada would have been decomposed to this depth at least. But the Klondike region is scarcely typical of northern Canada; its hills are higher than those in most of the rest of the country, and its surface is even now undergoing active atmospheric erosion, so that the products of surface decomposition are being continually carried down into the bottoms of the valleys. On the other hand, the surface over the Archean Shield of northern Canada had, in pre-Pleistocene times, been reduced almost to a peneplain, and therefore as its rocks became decomposed they would not be carried away so rapidly as on the more hilly country, and the thickness of soft weathered material should have been greater than on the hills of the Klondike. The decomposed rock covering the Archean peneplain was removed by the ice-sheet of the first Glacial period and spread out over the hills and plains around the edge of the glaciated area. Thus much of the detritus removed by the first ice-sheet was soft, rotten rock, and consequently in a powdered or friable condition, and not in the condition of boulders or fragments of undecomposed rock. The boulders and undecomposed rock fragments, which are so plentifully scattered in and through the till in the peripheral portions of the glaciated areas of North America, were probably plucked off and transported from the Archean Shield and its vicinity by later ice-sheets, and when some estimate can be made of the extent of this undecomposed material, a good basis will have been secured for a reasonable estimate of the quantity of erosive work performed by the ice-sheets of the second and later Glacial periods. Mr. Taylor is quite correct in stating that there is very little till in the more northern parts of Canada near the centers of glaciation; but in western Canada, at all events, there is a very wide belt of country heavily covered with till within the periphery of the glaciated area.

IOWAN DRIFT

BY SAMUEL CALVIN

(*Abstract*)

Three papers having more or less to say about the Iowan drift have appeared recently. Two of these express doubt as to whether there is an Iowan drift. The third raises the question whether, even if such a drift exists, the name it has been wearing should not be applied to something else. Taking up the question raised by the last of the three papers, an effort is made to show that the practice of applying the names Iowan and Kansan to two super-Aftonian drifts, a practice followed by geologists in recent years, is the only one at all consistent with the original texts and maps where these deal with the composition, color, and petrological contents of the two drifts named, or delineate their areal distribution. To shift the term Kansan to the sub-Aftonian till and the name Iowan to the first of the super-Aftonian drifts would involve the re-writing of the descriptive parts of the original texts and the re-drawing of the map opposite page 727 in the third edition of Geikie's "Great Ice Age." It accords better with what was published at the time the names were applied to let recent usage remain unchallenged and unchanged.

With reference to the attitude toward the Iowan drift assumed in the other two papers, facts from the field are presented to show:

1. The Iowan drift is.
2. The Iowan drift is young as compared with the Kansan.
3. The Iowan drift is not a phase of the Kansan.
4. The Iowan drift has certain very intimate relations to certain bodies of loess.
5. The Iowan drift has no close relations to the Illinoisan.

PLEISTOCENE OF THE VICINITY OF SIOUX FALLS, SOUTH DAKOTA

BY B. SHIMEK

(*Abstract*)

A discussion of the Pleistocene, including the Nebraskan drift (in some places more than 60 feet thick), the Aftonian silts and sand and gravel, the Kansan drift, a bluish post-Kansan loess, and a later yellow loess. The so-called Altamont moraine east of Sioux Falls is Kansan, and no Wisconsin drift was found in the region in question, either in South Dakota or in the western part of Lyon County, Iowa. There is no evidence of Wisconsin gravel trains along the valley of the Big Sioux, the gravels of the terraces being Aftonian. The buried gravel and silt near Sioux Falls, which have been referred with some doubt to the Buchanan, are Aftonian. The mammalian and molluscan Aftonian fossils of the region are discussed.

PLEISTOCENE OF THE VICINITY OF OMAHA, NEBRASKA, AND COUNCIL BLUFFS, IOWA

BY B. SHIMEK

(*Abstract*)

A discussion of the Pleistocene of the region, including the Nebraskan drift, the Aftonian, the Kansan drift, the post-Kansan loess, and a later yellow loess. A weathered form of the Nebraskan drift is described. The Loveland in places fully 50 feet deep. A comparison of the loess fossils from opposite sides of the Missouri.

LESSONS OF THE LITTLE YOSEMITE VALLEY

BY F. E. MATHES[3]

(*Abstract*)

Much of the diversity of opinion as to the eroding power of valley glaciers springs from a lack of definite knowledge regarding the exact manner in which ice excavates. There is still doubt as to which is the dominating process, plucking or abrasion. The Little Yosemite Valley affords unusual opportunities for studies bearing on this point. It is laid in granites of exceedingly varied structure, absolutely massive over large areas, but strongly jointed elsewhere. The Merced River being a superposed stream, the valley lies athwart

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[3] Introduced by W. H. Hobbs.

these structures and transsects both kinds of rock. Were abrasion the chief process, the ice would have worked with practically equal facility everywhere, regardless of structural differences, but the very opposite has manifestly been the case. It has achieved large results where the rocks were mostly fissile, but in massive rocks not susceptible to plucking and reducible only by abrasion, it has accomplished little indeed. Both in its major and in its minor lineaments, the valley exhibits striking evidences of this selective action. Thus, while it has been broadly opened for some distance, it is blocked at its lower end by massive domes that have remained standing like gigantic *roches montonnées*, although overtopped by the ice of at least two glacial periods. At its upper end, again, it contracts as the massive granite becomes more prevalent, and finally is reduced to a narrow winding gorge. These and other features are valuable as indices by which the efficiency of the ice as an eroding agent may be gauged.

TWO GLACIERS IN ALASKA

BY LAWRENCE MARTIN

(Abstract)

Among the glaciers studied by the National Geographic Society's Alaskan expedition of 1910 are two of unusual activity. Columbia glacier, in Prince William Sound, Alaska, began to advance in 1908, and has been visited on July 15, 1908, June 24 and August 23, 1909, June 30 and September 5, 1910, during which time its front has been progressing at an undetermined rate where tidal, but on an island and at the borders at the rate of from .9 to 2.1 feet a day, destroying forests and peat bogs and modifying marginal drainage and marine deposits. Childs glacier, on Copper River, was advancing at about its normal rate in August, 1909, the ice melting or discharging as icebergs into Copper River sufficiently fast so that the front remained nearly stationary. During the winter of 1909-1910, the rate of motion increased, a previously stagnant, shrub-covered part of the margin visibly advancing into the forest at the rate of 2 to 8 feet a day during June to October, 1910, when it was re-mapped at frequent intervals. Independently of this increased rate of advance, the position of the ice front in the river has oscillated during the summer with the stages of water in Copper River. A $1,400,000 steel bridge and the key to a railway system is threatened by this advance.

Discussion

Prof. R. S. Tarr asked whether the ice of the advancing glacier pushed beneath the soil and forest or whether it merely shoved the soil ahead.

Professor Martin replied as follows: No such projections of the advancing ice front were seen, but their presence was suggested by the overturning of trees before the glacier reached them and by the carrying forward of material as if on the projecting snout of a glacier.

Professor Martin replied as follows to a question by Mr. Brooks: There is present movement in the Allen (formerly Baird) Glacier, faster in the clear ice portion near the mountain valley than in the expanded bulk, covered with moraine and vegetation and traversed for 5 miles by the railway.

SYSTEM OF QUATERNARY LAKES IN THE MISSISSIPPI BASIN

BY E. W. SHAW[4]

(*Abstract*)

In the northern part of the Mississippi basin there are certain thick bodies of clay and certain physiographic features which indicate a great system of extinct lakes extending from southern Wisconsin to eastern Kentucky. The clay lies at low and concordant altitudes and occupies an aggregate area of several thousand square miles. The physical character, horizontal attitude of the surface, shore features and fossils show that the material is of lacustrine origin, and it appears that the lakes were formed through the rapid development of valley trains on the Mississippi and Ohio rivers in late Glacial time, the debris damming the lower ends of tributary valleys. The lake deposits are thus "valley fillings," ranging in thickness up to over 100 feet. In each valley the surface of the fill is practically horizontal, but the altitude of the surface varies from valley to valley. The height increases regularly from Cairo up the Mississippi and from the same point up the Ohio. The height, and hence the extent of the water in each lake, being controlled by the river. fluctuated as the river rose and fell; but the lakes served as reservoirs, so that the range between high and low water was not so great as it would otherwise have been. Shore features were generally poorly developed, but in places, as near Madisonville, Kentucky, there are unmistakable beach ridges.

Discussion

Prof. R. D. Salisbury: Deposits of the sort referred to by Mr. Shaw have been known at various points along the Mississippi for many years, but they have not been interpreted generally as certainly lacustrine. While some of the deposits bear the marks of lacustrine origin, others bear the marks of a sluggish fluviatile origin, and lacustrine and river phases of deposition alternate frequently in the same valley. In some of the valleys with which I am familiar, lacustrine, swamp and river conditions of deposition seem to have alternated. Great caution is necessary, therefore, in classing deposits of the sorts referred to as wholly lacustrine. On the other hand, the fact that conditions of deposition changed from time to time in some valleys, is no proof that the deposits referred to by Mr. Shaw are not strictly lacustrine.

Mr. Shaw replied as follows: In reply to Professor Salisbury, I wish to say that we do find both stream and lake deposits and every stage of gradation between. I touched on this point but briefly in order to avoid confusion. The Monongahela here at Pittsburgh and other streams—for example, a small one in the extreme northwestern corner of Illinois, in the area of which Professor Salisbury speaks—were not ponded, but were able to build up as rapidly as the overloaded master streams. In these cases the deposits contain coarse material, show irregular stratification, and the origin is not so clear, for some streams with low gradients carry only very fine material, and when they aggrade they form a deposit with an almost, though not quite, horizontal upper surface. But the deposits described in the present paper seem to have

[4] Introduced by David White.

a perfectly horizontal valley side edge, and some of them are more than 50 miles long. I have no doubt but that at the same time lake and stream deposits were accumulating in different places, and also in the same place at different times, but the great extent of the horizontal upper surface, the fineness of the material and regularity of stratification, the fossils, and the shore features where developed seem to me to show conclusively that most of the filling on many of the streams tributary to the Mississippi and Ohio was laid down in quiet ponded water.

RADIATION OF GLACIAL FLOW AS A FACTOR IN DRUMLIN FORMATION

BY WILLIAM C. ALDEN

(*Abstract*)

This discussion is based on the relations of the moraines and drumlins of the south half of the Green Bay glacier of eastern Wisconsin. There is a very notable development of drumlins which are grouped in three more or less distinct sets. Corresponding to each is a set of marginal moraines believed to mark the limits of the glacial lobe during the stages when the drumlins were being formed. The outer moraine of each set marks the limit of a readvance of the ice following an interval of recession. The drumlin belts in each case are confined to distances of 30 to 35 miles from the south end of the lobe—that is, to that part where the ice was radiating widely to the curved margin of the lobe and where it was thinned in consequence of the radial spreading and of loss by melting and ablation.

The computations of the probable elevation of the surface of the glacier were based on the known thickness of the ice within four miles of the margin where the Baraboo quartzite range was over-ridden and on an estimated average slope for this surface of 50 feet per mile in the first 25 miles, including the initial rise of 700 feet in the first four miles and allowing an average of 20 feet per mile thereafter. Deducting from these the present elevation of the land gives a thickness of ice varying from 1,450 feet over the initial part of the first drumlin belt to 450 to 830 feet, where drumlins ceased to be formed within five miles of the limit of ice advance. The drumlin-forming ice stream had an initial width at *A* of 17 miles where radiation began. In advancing 15 miles this expanded to a width of 32 miles at *B*, and at the terminal moraine the expansion gave a marginal arc of about 100 miles. Computations show that in spreading to the width at *B*, while at the same time maintaining the requisite thickness and low surfical slope, the cross-section of the stream must have increased to 1.603 times the area of the initial section, and, inasmuch as no tributary stream had added to the volume, the rate of flow must have been faster at *A* than at *B*. At *C*, where the drumlin formation ceased, the arc of the stream had expanded to 85 miles and the cross-section was 2.325 times that at *A* and 1.45 times that where drumlin formation began. From these figures it is evident that the spreading of the ice under its own weight alone would not account for the remarkable expansion. Only the forward crowding of the more rapidly moving ice in the rear could have supplied the requisite volume. Though the stream expanded greatly so that friction was much increased, the remarkable development of drumlins indicates that

the basal ice did not clog. Such basal movement was probably due to the ice being shoved bodily forward by the vigorously advancing ice in the rear, this forward shove being superimposed on such internal flowage as was taking place. It is believed that the application of such propulsive force in the region of the center of radiation of such a mass, which was tending to lag in every part, owing to great friction, would tend to cause the longitudinal lines of flowage to spread and so develop stress along transverse lines. These stresses, though perhaps not causing the actual opening of longitudinal crevasses, would facilitate spreading of the ice about obstructing piles of drift and their being shaped into drumlins rather than their obliteration by erosion. It might also induce localized deposition in piles or ridges which would later be shaped and might be added to by the plastering on of drift. Computations based on the ice streams forming the second set of drumlins show the radiation to have been even more marked than in the first case with correspondingly greater crowding forward of the faster moving ice in the rear and more marked development of drumlins. Comparison with segments of the glacier which had equal initial widths, but did not form drumlins, shows that in the latter there was very moderate radiation and that, unless the ice in the rear was moving more slowly than that in front, there was a decrease in the volume of the stream as it advanced, as opposed to the increase in volume of the drumlin-forming stream. With the radiation fully accounted for by the spreading of the ice under its own weight and with no forward crowding of the ice in mass there would be absence of lateral stress and of the tendency to longitudinal crevassing, and this may explain the absence of drumlins. Other factors than radiation are probably also involved.

Discussion

Prof. H. L. Fairchild: For Dr. Alden's paper and its illustrations and manner of presentation, I have great admiration. It is interesting to note the similarity in all important features between the Wisconsin and the New York drumlins. The production of these singular masses of drift evidently depends on the combination of several factors which do not commonly occur over the glaciated field, one important and essential factor being the movement of the ground contact ice due to thrust or push of the rearward ice. The amount of basal drift necessary to construct drumlins is probably prohibitive of free or gravitational flow of the burdened ice on gentle slopes. As drumlins in New York lie on slopes facing or opposing the ice advance, the movement necessary to vigorously mold the ground moraine could not be produced merely by the gravity of the drumlin-shaping ice. The only point in Dr. Alden's fine discussion that I would question is the causal relation of the spreading or radial flow of the ice to the drumlin-building process. In several localities in New York we have groups of drumlins where the ice did not have spreading movement. I should say that the radial movement of the ice was an accompaniment of the more favorable drumlin-forming conditions, but not an essential factor,

NEW METHOD OF CALCULATING THE DATE OF THE GLACIAL EPOCH

BY RUFUS M. BAGG, JR.

(*Abstract*)

The antiquity of the Ice age can possibly be determined by the rate of peat formation upon Block Island. The peat beds lie in practically unchanged glacial kettle hole basins which are believed to have begun to form immediately upon the recession of the ice margin in New England. These basins have been undisturbed by natural drainage and afford unusual facilities for calculating the date of the Ice epoch based upon the peat infilling overlying the glacial till of the island.

The paper dealt with the problem of peat formation in a limited manner, laying particular stress upon the time factor under conditions known to exist in New England.

The reasons why this method would not hold in other localities were set forth in the paper as submitted.

PHYSIOGRAPHIC STUDIES IN THE SAN JUAN DISTRICT OF COLORADO

BY WALLACE W. ATWOOD

(*Abstract*)

After a brief season in the core of the San Juan Mountains during the season of 1909, plans were made for a detailed physiographic survey, in 1910, of the southern and southwestern slopes of the range. Remnants of an ancient peneplain have been mapped. They have an elevation of about 8,000 feet in the mesa-plateau district bordering the range and increasing elevations up to at least 11,000 feet on the mountains. Small beautifully rounded pebbles rest at many places on the peneplain remnants in the mountains, but south and southwest of the range the peneplain remnants are mantled by a coarse boulder-gravel formation. The boulder-gravel formation extends at least 50 miles from the base of the range, and may prove to be an important horizon in correlating the physiographic histories of the San Juan range and the Colorado plateau. Later stages of erosion and glaciation are recorded by appropriate features and deposits. The physiographic studies may make certain important contributions to the interpretation of the late Tertiary and Quaternary deformations of the San Juan dome.

Discussion

Mr. Rich: Along the northern flank of the Uinta Mountains is a gravel-covered peneplain probably to be correlated with the higher peneplain of the San Juan area. The general characteristics and age relations confirm Mr. Atwood's suggestion that peneplains similar to the San Juan may be found in connection with other Rocky Mountain ranges.

Prof. W. M. Davis remarked on the nicely rounded pebbles of the peneplain surface.

GEOGRAPHICAL DESCRIPTIONS IN THE FOLIOS OF THE GEOLOGIC ATLAS OF THE UNITED STATES

BY W. M. DAVIS

(Abstract)

The Folios of the Geologic Atlas of the United States usually open with an empirical geographical description of the district concerned, and on a later page give, under the appropriate heading, Historical Geology, an explanatory account of the evolution of the same features. Under the second heading we find some of the best examples of modern treatment of physiographic evolution; but under the first heading we find an undue conservatism in the retention of old-fashioned empirical terms in place of more recently introduced genetic terms. In the treatment of the geological problems, which naturally occupy the greater part of the text, explanatory treatment phrased in modern technical terms is entered upon at once, as it should be. A similar explanatory treatment of geographical features in technical terms would be consistent with the recent progress of geographical research.

QUANTITATIVE CLASSIFICATION OF METEORITES

BY OLIVER C. FARRINGTON

(Abstract)

Earlier systems of classification of meteorites are reviewed, and the results of classifying meteorites according to the quantitative system are given. The number of meteorites classified reaches about one hundred and twenty-five. The meteorites are all, except one, in the classes of dofemanes and perfemanes. The dofemanes are persilicic, dosilicic, and silico metallic; the perfemanes range from persilicic to permetallic. Nearly all are perpolic. From perpyric all gradations occur to perolic. All are permirlic. Most are permiric and domagnesic. While the majority fall outside of the groups in which terrestrial rocks occur, the groups of wehrlose, argeinose, maricose, and websterose are represented.

MOLDAVITE QUESTION

BY GEORGE P. MERRILL

(Abstract)

The paper discusses the supposed meteoric origin of the peculiar glass bodies known under the names moldavite, billitonite, australite, obsidian bombs, etcetera, and shows that the peculiar surface markings are closely comparable to etchings produced by solfataric emanations or natural weathering, and not at all like those on known meteorites. A new form from South America is described.

CLINTON SAND AS A SOURCE OF OIL IN OHIO

BY J. A. BOWNOCKER

(Abstract)

The stratigraphical position of the Clinton sand, its thickness, texture, and other physical properties. Geographical area where found. Areas producing

oil. Relation of these areas to rock structure. Character of the oil. Probable extensions of the producing territory.

Discussion

Dr. F. G. Clapp: In reference to the probability of the so-called Clinton sand being Medina in age, I wish to mention a well recently drilled in extreme northwestern Pennsylvania which found gas in what seems to be the same formation and in the Medina sand which is productive in western New York. I also wish to ask Mr. Bownocker whether the oil at Butler, Ohio, had similar structural relations to other oil pools in the Clinton sand.

Reply by Dr. Bownocker: Yes, so far as I have been able to determine.

GEOLOGICAL RELATIONS OF OIL POOLS SITUATED IN REGIONS OF MONOCLINAL STRUCTURE

BY FREDERICK G. CLAPP

(*Abstract*)

Particular reference was made to the oil pools of southeastern Ohio, which may nearly all be classified as situated on monoclinal structures. Geologists and oil men have generally assumed that geological structure was of little assistance in predicting the positions of pools of this class. The main object of this paper is to show that geology is of great value in this, as in other classes of oil fields, and that good predictions may be made. The detailed structures of several well known oil pools are given as examples. It has been discovered that in the great majority of cases the oil has accumulated at positions where the change in rate of dip is locally pronounced, and that the size and productivity of the pools is commonly proportional to the abnormality of the generally uniform dip. The positions of accumulation are also influenced by structural "ravines" crossing the sand. Although the structure of the sand may be quite different from that of the surface formations, it can, nevertheless, be calculated to a considerable degree of accuracy from the surface, by taking into account the change in intervals, which is comparatively uniform for a given locality.

Discussion

Mr. C. W. Washburne: Stratigraphic structure is the essential element in the study of most oil fields, and the proposed classification is useful because of the aid it gives in impressing the main structural relations on the mind of a student. The true facts are thus presented regardless of theory. However, by over emphasis of stratigraphic structure, joints and fissures may be overlooked. Is it not possible that geologists pay too little attention to some of the prevalent opinions of drillers, such as their belief that fissures and joints play an important rôle in many fields? Where the oil occurs wholly in joints and fissures, as in the Florence, Colorado, oil field, stratigraphic structure is of little importance, and it is meaningless to call the field a monocline. An additional heading should be provided for synclinal fields, such as the new San Juan field of southeastern Utah.

GEOLOGY OF THE CHIBOUGAMAU REGION, QUEBEC, CANADA

BY ALFRED ERNEST BARLOW

(*Abstract*)

The region described is underlain by rocks of Archæan or pre-Cambrian age. These are included in the Keewatin, Laurentian, and Huronian formations. In addition, an intrusive rock which seems peculiar to this area has been referred to the gabbro-anorthosite, because although it is of gabbroic type, there is in general a marked absence or paucity of the ferromagnesian minerals usually so abundant in gabbros. In this respect, it resembles the anorthosite formerly classified as upper Laurentian, but is more acidic. The geological relations of these formations will be discussed, as also the origin and mode of occurrence of gold-bearing quartz veins, asbestos-bearing serpentines and certain deposits of chalcopyrite, pyrrhotite, and magnetite.

OCCURRENCE OF SILVER, COPPER, AND LEAD ORES AT THE VETA RICA MINE, SIERRA MOJADA, COAHUILA, MEXICO

BY FRANK R. VAN HORN

(*Abstract*)

These ores occur on the contact or a short distance below the contact of an acid breccia with an underlying limestone of Cretaceous age. There are some indications of a fault plane between the two rocks, such as clay selvages and slickensides. There are two types of ore, a silver-lead and a silver-copper series. In the former group, the minerals are all oxidized and consist chiefly of argentiferous cerussite along with native sulphur and some gypsum. The bulk of the ores from this mine, however, seems to belong to the silver-copper group and contains sulphides as well as oxidized minerals. Minerals noticed here were chalcopyrite, chalcocite, covellite, along with native copper, malachite, azurite, cuprite, and gypsum. Another zone consisted of a siliceous limestone containing up to 10 per cent of barite which was impregnated with cerargyrite and native silver. Here the copper content was smaller and rarely exceeded 2 per cent. Some three years ago, a fault was discovered in the northern part of this "silver-lime" ore body. Along this fault plane silver and copper minerals of great richness were found mixed with more or less barite. Some of the minerals noticed were native silver, argentite, proustite, and pearceite which has been found in but two or three localities in the world. At this point a mixture of erythrite and barite was also noticed, which seems to be the first observation of cobalt minerals in the district.

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